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Approach to technology prioritization in support of moon initiatives in the framework of ESA exploration technology roadmaps

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ABSTRACT

Exploration technology roadmaps have been developed by ESA in the past few years and the latest edition has been released in 2015. Scope of these technology roadmaps, elaborated in consultation with the different ESA stakeholders (e.g. European Industries and Research Entities), is to provide a powerful tool for strategic, programmatic and technical decisions in support of the European role within an International Space Exploration context. In the context of preparation for possible future European Moon exploration initiatives, the technology roadmaps have been used to highlight the role of technology within Missions, Building Blocks and Operational Capabilities of relevance. In particular, as part of reference missions to the Moon that would fit in the time frame 2020 to 2030, ESA has addressed the definition of lunar surface exploration missions in line with its space exploration strategy, with the common mission goals of returning samples from the Moon and Mars and expanding human presence to these destinations in a step-wise approach. The roadmaps for the procurement of technologies required for the first mission elements of the above strategy have been elaborated through their main building blocks, i.e. Visual navigation, Hazard detection and avoidance; Sample acquisition, processing and containment system; Surface mobility elements; Tele-robotic and autonomous control systems; and Storable propulsion modules and equipment. Technology prioritization methodologies have been developed in support of the ESA Exploration Technology Roadmaps, in order to provide logical and quantitative instruments to verify choices of prioritization that can be carried out based on important, but non-quantitative factors. These methodologies, which are thoroughly described in the first part of the paper, proceed through subsequent steps. First, technology prioritization's criteria are selected; then decision trees are developed to highlight all feasible paths of combination of technology prioritization's criteria and to assess the final achievement of each path, i.e. the cost-effectiveness. The risk associated to each path is also evaluated. In the second part of the paper, these prioritization methodologies have been applied to some of the building blocks of relevance for the mission concepts under evaluation at ESA (such as Tele-robotic and autonomous control systems; Storable propulsion modules and equipment) and the results are presented to highlight the approach for an effective TRL increase. Eventually main conclusions are drawn.

1. Introduction

All around the world, agencies and industries in many fields are facing the problem of technology roadmapping to show in a clear view the set of target to reach and to clearly identify the critical system requirements, the product and process performance targets, the technology alternatives and the milestones. This is true also in the space sector.

Moreover, technology planning is also an important help for decision makers considering the competitive problems that many companies and agencies are facing: technology roadmapping is a form of technology planning that can be used to compare at the same time many parameters and situations and to optimize the final planning [1]. In this contest, exploration technology roadmaps have been developed by ESA in the past few years and the last edition has been released in 2015. Scope of these technology roadmaps, elaborated in consultation with the different ESA stakeholders (e.g. European Industries and Research Entities), is to provide a powerful tool for strategic, programmatic and technical decisions in support of the European role within an International Space Exploration context.

Many references can be found in literature that, referring to space

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Nomenclature

ℕ	Natural numbers
ℝ	Real numbers

Acronyms/abbreviations

AD2	Advancement Degree of Difficulty
AHP	Analytic Hierarchy Process
BB	Building Block
ESA	European Space Agency
FoM	Figure of Merit
HERACLES	Human Enhanced Robotic Architecture and Capability for Lunar Exploration and Science
IRL	Integration Readiness Level
LEO	Low Earth Orbit
MC	Mission Concept
OC	Operational Capability
TA	Technology Area
TRL	Technology Readiness Level
SoS	System of Systems

exploration technologies, report the current technological state of the art for different space players [2–7]. In all these references, as well for ESA, the Moon is becoming in recent years a competitive target to reach, both for scientific reason and for technological demonstration. Indeed, reaching the Moon can be a good target point to demonstrate the readiness level of technologies enabling interplanetary missions, for example for Mars [8–10]. In particular, as part of reference missions to the Moon that would fit in the time frame 2020 to 2030, ESA has addressed the definition of lunar surface exploration missions in line with its space exploration strategy, with the common mission goals of returning samples from the Moon and Mars and expanding human presence to these destinations in a step-wise approach.

A methodology has been developed to generate roadmaps to eventually support strategic decisions for human space exploration and this methodology has been applied to the ESA Moon reference mission. The proposed methodology is intended to be a semi-automatic process for technology roadmaps definition and update according to the user needs. However, unlike [11] or [12], this paper does not focus on the results of space exploration roadmaps or on the methodology developed to drive their creation and update and for this reason the final suggested roadmap will not be presented. The main purpose of this particular work is to focus deeper on the characterization of the proposed methodology bricks, particularly of Technologies. Indeed, to elaborate the right roadmap, many parameters have to be considered at the same time. For example, a technology roadmap definition process has to relate with current or changing limitation of financial resources by both the government and industry, with scientific or technical needs and with current general public requests. In order to correctly propose a TRL increase path, financial limitations and stakeholders needs have to be considered: to this purpose, a prioritization of the lists of identified bricks is required to consider them with the right priority. Strategic decision makers need a method to assist them in the prioritization of investment in advanced technologies.

Technology prioritization methodologies have been developed in support of the ESA Exploration Technology Roadmaps, in order to provide logical and quantitative instruments to verify choices of prioritization that can be carried out based on important, but non-quantitative factors. Generally, three main steps (Fig. 1) can compose a technology prioritization study. Firstly, inputs have to be established, usually from technology roadmaps and roadmaps' elements derivation methods. In this phase, technologies are listed but not ordered according to any ranking criteria. Secondly, prioritization methods and criteria have to be chosen, usually through stakeholders' interactions and trade-off analyses. In this phase is also important to define constraints or Figures of Merits (FoM) that might have an influence on the result: these parameters will have an important role in trade-off and sensitivities analysis in order to correctly size the result. Finally, applying criteria, methods and constraints, an ordered list of technologies can be obtained and can be used as input for technology roadmaps definition, decision makers' analysis and TRL increase path evaluation.

A wide number of prioritization methods specifically designed to assist agencies with this very challenge have been developed and widely used in a range of industries in different fields [13–15]. In literature can be found both methods based on the modeling and simulation of physical and economic processes and methods based on the judgment of a set of stakeholders to compare various alternatives for each criterion of interest [13]. The main core of these methods is to have subjective human beings involved in the prioritization loop, together with objective tools and criteria [13]. In order to reduce the uncertainties in the prioritization problem and to increase the probability to achieve optimal results, employing a defined prioritization technique can provide a structured mechanism for objectively ranking technologies and situations. Qualitative and quantitative methods exist to help the decision maker evaluating alternate futures through the optimal mix of new technologies. These kinds of method derive from decision analysis, as for example, Analytic Hierarchy Process (AHP), Multi-voting Technique, Strategy Grids, Nominal Group Techniques, Decision Trees [15] and Prioritization Matrix [14]: all these prioritization methods have been analysed in order to find and propose a structured and logical process able to face with stakeholders limitations and optimization criteria together with technological risks and budget analysis. The results of this analysis are here proposed. This proposed process is part of the methodology developed for the development and update of technology roadmaps: indeed, a prioritization of the roadmap bricks is clearly an input for the proposal of the TRL increase path and needs to use as input itself the main characterization of the bricks obtained through this methodology in order to be compliant with the final results (i.e. the roadmap).

The methodology that has been built for the technologies assessment

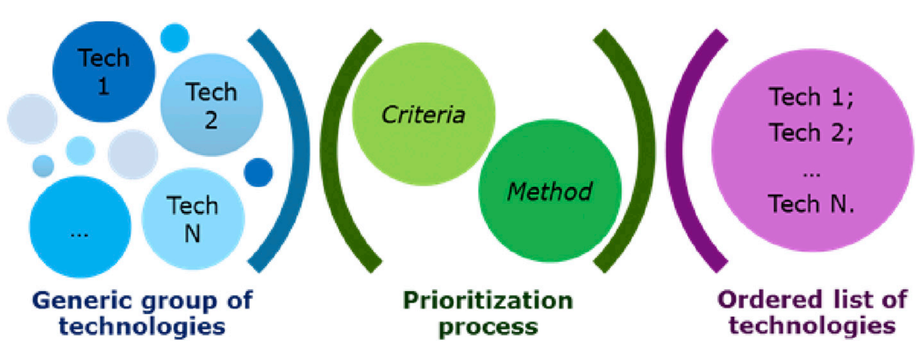

Fig. 1. Prioritization studies generic scheme.