Generative Sensing and Seizing Model

An adaptive dynamic development framework as a tool for strategic orientation in aerospace organizations

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***Abstract*— In times of discontinuous change, aerospace organizations, complex and regulated, face situations of uncertainty, in which they need the flexibility to renew their technological strategy. The aerospace market is highly competitive and technology-intensive, requiring organizational ambidexterity, which seeks to improve the ability to identify changes in the environment and select an innovative technology portfolio. The article proposes the development of a strategic model, dynamic and adaptive, to improve the success of long-term technological definitions through the opportunities sensing and seizing. The generative sensing and seizing model, based on dynamic capabilities, seeks to improve decision-making over a long-term horizon and the fungibility of the deployment of strategic actions concerning the selection of technologies. The research is based on case studies explored in prospection, and research and development sectors at Embraer. It seeks to take advantage of conditions of uncertainty as a potential source of change in the strategic development of future possibilities.**

I. Introduction

In an environment of discontinuous changes [1], [2], [3], [4], [5], a technological strategy can impact the growth and sustainability of organizations that seek to adapt to changes in the environment and capture opportunities [6].

Globalization and technological change are important sources of competition in markets increasingly complex, unpredictable and connected. This scenario requires organizations to develop mechanisms that allow the monitoring of future trends and the rapid reaction to the movements of competitors and highlights the importance of forecasting as a determining factor of competitive advantage. Technological changes represent one of the most relevant factors of organizations' competitive advantage and face challenges that go beyond forecasting trends. These challenges lie in the complexity of the relationships between technologies, government policies, and organizational strategy [7].

Research related to strategic factors considers the resource-based view [8], [9], [10], [11], which with the evolution of economic and administrative research in complex environments has generated the concept of dynamic capabilities [2], [12], [13], [14], [15], [16], [17]. The theory of dynamic capabilities contributed to a better understanding of the adaptability of organizations, but not to the choice of investments among capacities [16].

In the field of aerospace technologies, the development time, from the initial stages to the application of the technology in the product, can take about ten or even 20 years, if successful. And to stay ahead of the competition in this complex and competitive market, these organizations must invest in the development of technologies with low maturity and capabilities [18].

The article explores the characteristics of decision making in complex systems, expanding the concept from generative sensing to generative sensing and seizing (GSS), based on dynamic capabilities. The model associates these capabilities with the metrics of TRL (Technology Readiness Level) and seeks to improve strategic decisions and the way to deal with ontological uncertainty [19] concerning different types of investments. The article aims to explore the conditions of ontological uncertainty and flexibility in the development of technology strategy in the aerospace industry, based on dynamic capabilities.

II. Literature Review

A. *Dynamic Capabilities (Inside-out strategy)*

The evolution of the concept of the resource-based view [8], [9], [10], [11] to dynamic capabilities [2], [12], [13], [14], [15], [16], [17] led to the integration of organizational and strategic routines in the reconfiguration of its resource portfolio [3]. The term dynamic refers to the ability to renew competences, and capacities, to the organizational skills of integrating, adapting, and reconfiguring resources [2].

Dynamic capabilities, defined as organizational and strategic routines of organizations that seek to achieve new configurations through resources to be combined to create changes in the market [3], emerged as a structure that aims to explain how organizations act to adapt to the environments [4], [13]. These conditions require organizations to develop more dynamic mechanisms to ensure competitive advantage and economic growth [20].

Dynamic capabilities substantiate the strategic development of organizations [2], [12], [13], allowing for the necessary agility to deal with uncertainty [15]. These capabilities are a strategic approach that explains how organizations adapt and reconfigure their dynamic and operational capabilities to respond and anticipate changes [15], seizing opportunities, and maintaining competitive advantage in a market of discontinuous changes [3]. The secret to the competitive advantage of some successful organizations lies in a strategy that favors the capture of opportunities [21], [22].

Teece [13] divided dynamic capabilities into three main elements: sensing, seizing, and transforming. In the current business environment, more and more companies are concerned about adapting to turbulent environments and identify opportunities that these environments can offer. Sensing and seizing these opportunities are two of the three groups of dynamic capabilities covered in this article.

B. Ontological uncertainty

Subjective probability requires creating antecedents based on current knowledge of future possibilities, whose relative probabilities are updated as new information is revealed over time [23]. Ontological uncertainty, which results from the individual's lack of knowledge about the future [24], refers to changes in reality, which may have been caused by a strategic definition [19].

One source of uncertainties is the surprises that result from what is currently unknown, and another is the reflexivity caused by cascades of decisions in response to emerging developments [19], [23].

Simple contexts can result in a multiplicity of possible future states because of reflexivity and beliefs are the key to which the future arises, and decision-makers manage those beliefs, shaping the process of change for some end states and not for others [19].

C. Technological Readiness Level (TRL)

The management of investments in technology is fundamental to the success of projects and programs. It is based on arguments that they can reduce uncertainties related to performance, time, and cost [25], [26].

The TRL structure, by Mankins [27], is divided into nine levels of maturity: (1) basic principles observed and observation and reported; (2) technological concept and/or application formulated; (3) analytical and experimental critical function and/or characteristic proof-of-concept; (4) component and/or breadboard validation in laboratory environment; (5) component and/or breadboard validation in relevant environment; (6) system/subsystem model or prototype demonstration in relevant environment; (7) system prototypr demonstration in a space environment; (8) actual system completed and flight qualified throught test and demonstration; (9) actual system flight proven throught successful mission opperations.

The TRRA model (Technology Readiness and Risk Assessment) includes technological development and the elements of risk analysis at each TRL level [26], [28], consolidating the TRL levels, the degree of difficulty in R&D (R&D3), and technology need value (TNV), which assesses the importance of developing a technology for the success of the program.

The most critical decision-making concerning investments in R&D is to assess whether the technologies necessary for the system have collectively reached the point of maturity, risk, uncertainty, and performance required to continue the development of the system, which can impact success or failure of programs [26].

D. Ambidexterity

Contemporary organizations are inserted in a scenario characterized by environmental pressures, transformations, risks, uncertainties, and ruptures. In this context, technological strategy and market adaptation capabilities can guarantee better chances for growth and survival for organizations [29], [30].

Organizations that have the competence to consider market demands (demand pull) and the development of new technologies (technology push) concurrently are called ambidextrous [30], [31]. These organizations can assess the incremental needs demanded by the market in the short term and generate knowledge through long-term R&D.

This balance can be one of the most difficult of all strategic challenges and requires decision-makers to explore new opportunities, even if they work to exploit existing capabilities [31]. An organization's ability to exploit its current business while exploring a new market has been recognized as a critical source of competitive success [3], [29], [32].

In this same line of research, March [32] introduced concepts related to the prospection of new knowledge (exploration) and the use of existing knowledge (exploitation). It also emphasized the importance of balance between them. The exploration concept includes the search for new opportunities, and the exploitation concept includes incremental changes.

III. METHODOLOGY

The method defined for this research was the study of multiple cases. Case studies allow for the recognition of patterns between cases and the relationships between them, a better understanding of events, tests of existing theory, and the development of a new approach [33], [34]. Therefore, the case study represents an opportunity to apply and analyze the benefits of the proposed model. It can also improve understanding of the influence of uncertainties on decision-making processes.

The study considers the combination of inductive and abductive logic to deal with the uncertainties inherent in the R&D environment. Induction represents the reasoning that results from inference and leads to the truth in the long run. Abduction represents a process of inference used to explore data, identify patterns, suggest hypotheses, and allow for discoveries [35]. Peirce [36] defined abduction as a reasoning constructed from an unknown future state.

The data collection was made in the last four years, with researchers, development engineers, and leaders from the prospection and technological development sectors of Embraer, a Brazilian aerospace company. The study contemplated the details of the technological development strategy through the analysis of documents, research, and interviews. This detail seeks to improve the understanding of the relevant aspects of the definition of technological portfolios.

IV. CASE ANALYSIS

Organizations seeking to improve their strategic management practices often carry out the benchmarking process in many areas, including research and development [5].

In this way, modeling dynamic capabilities can help to improve understanding of how an organization's superior capabilities could contribute to capacity building for the future [37].

This study, which is part of a doctoral thesis, seeks to assess the needs of organizations regarding the development of a technological strategy based on prospection. Topics explored at this stage in the development of the research include (1) uncertainties and emerging properties, (2) complexity of the environment and systems, (3) a corporate culture, (4) long-term strategic planning, and (5) dynamic capabilities. The cases explored, distributed on the map of dynamic capacities and technology readiness level (TRL), are shown in figure 1:

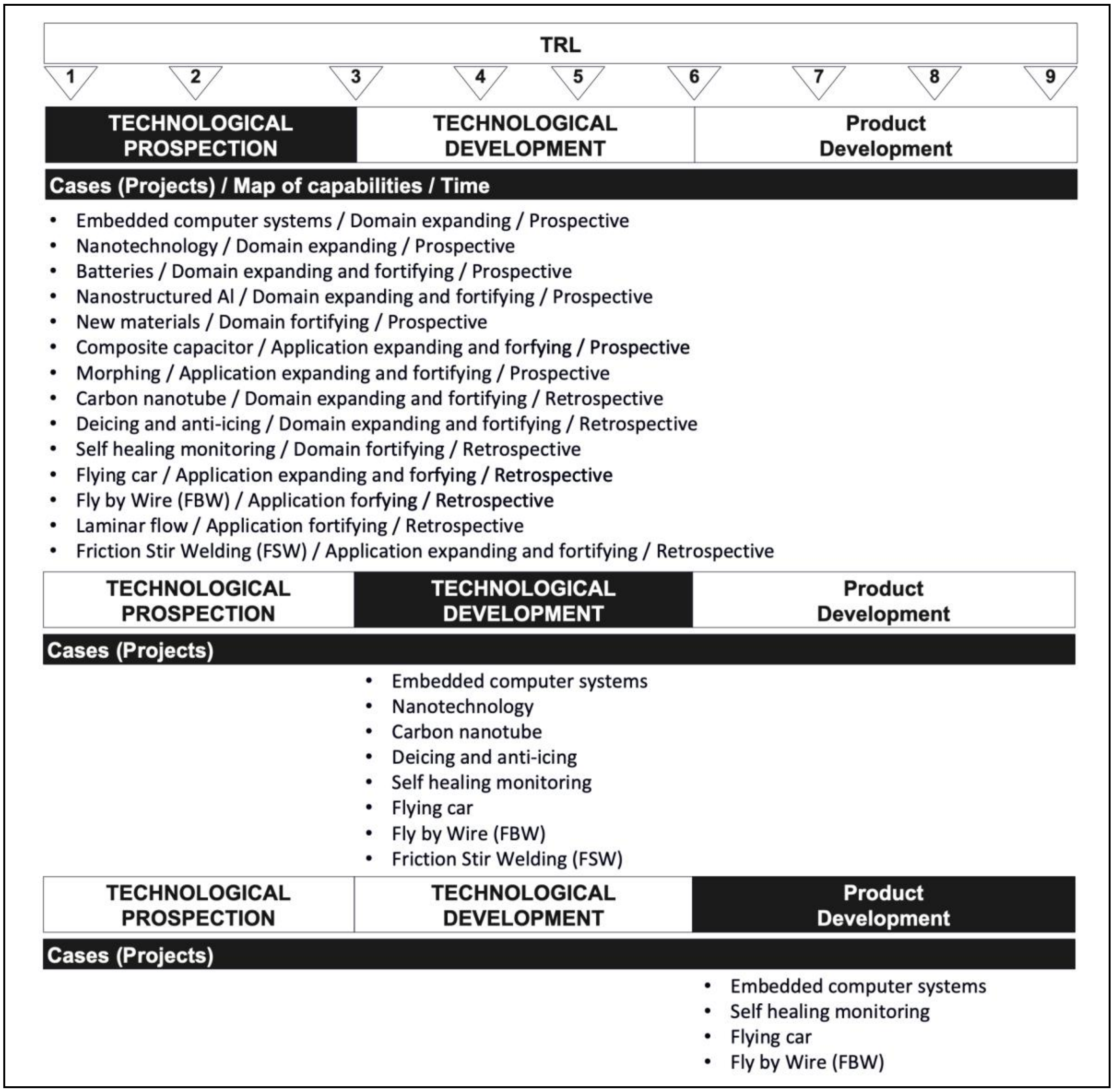

Fig. 1. Cases distributed on a map of dynamic capabilities and levels of technological maturity (TRL)

The study highlights that Embraer, which is the focus of this study, has a well-structured and robust engineering capacity in several areas, from integration to verticalization of technological developments. Realizing the frequent changes, the organization sought to use its capabilities to adapt (inside-out strategy) to each new condition, not the other way, which would be looking at the market and the world, identifying opportunities, and then adjusting its capabilities.

The map of capacities shows that, in the prospection stage, capabilities are well-diversified, always seeking to learn within a general-purpose, due to the low maturity of technologies. In the technological development stage, Embraer invested more in a specific market because it is focused on the application of technologies in the aerospace sector. In some cases, it opted for the expansion of capabilities but oriented towards the aeronautical and/or defense sectors, for example.

V. Generative Sensing and Seizing (GSS) Model

Recently, new tools have emerged to deal with uncertainties [19], such as Dynamic Adaptive Policy Pathways [38], [39]. This market of discontinuous changes, high complexity, and uncertainties requires more agility in the responses of organizations, to improve the performance of strategic definitions [20]. These definitions depend on decision-makers, who must create a vision of the future [38] and adapt their strategic plans to the new reality [40], [41] from situations of uncertainty [42]. In the Dynamic Adaptive Policy Pathway (DAPP), the policy itself, which is an essential component of total uncertainty [38], constitutes an acknowledgment of reflexivity [19]. The development of the GSS model used previous research to identify the criteria used in the technology strategy, and the case studies contributed to complement these criteria (figure 2). The model, under development, is structured in five parts.

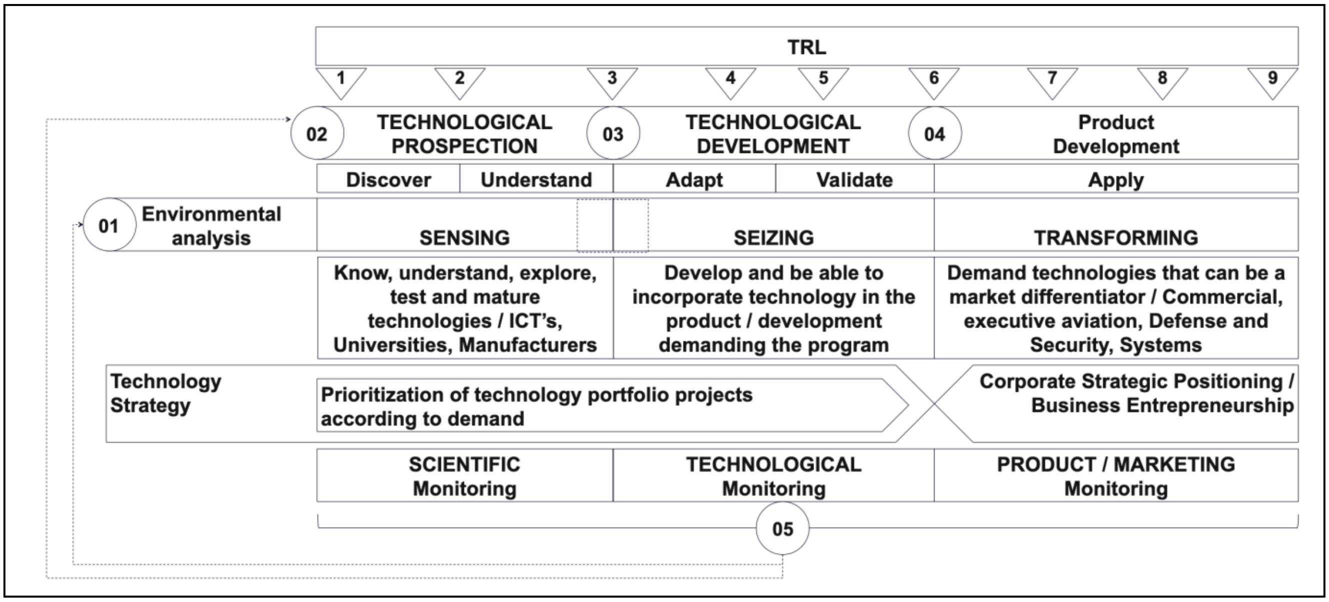

Fig. 2. Generative Sensing and Seizing (GSS) Model

Stage 1 includes the analysis of the environment and contingency factors and seeks a better understanding of the organization's needs, strategic gaps, and possibilities for technological development (technological gaps). This analysis includes the nature of the strategy, the corporate culture, the sources of competitive advantage, and the complexity of the environment.

At this stage, it is essential to read the main challenges for future competitiveness through the collection, analysis, and consolidation of information.

The second stage, referring to technological prospection (TRL 1-2-3), involves scientific and technological monitoring, generating a multitude of possibilities for new technologies, which through the generation and testing of hypotheses, must be classified, prioritized, and recommended. This stage favors the grouping of similar technology, which may be funded by different sponsors, organizations, industries, and is a crucial way to overcome constraints, leveraging additional resources and investigating a significantly higher volume than would be possible individually [18]. Stage 2, which involves low-maturity technologies, is characterized by significant uncertainties, high risks, and the possibility of testing the technologies in the early stages of development, at lower costs.

This stage has a high impact on capacity building for the organization and should guide the construction of the technology portfolio and development priorities.

Stage 3, technological development (TRL 4-5-6), represents the main link between technological strategy and corporate strategy. Therefore, it seeks to improve the alignment of technology push and demand pull strategies, highlighting the importance of ambidexterity in the technological strategy of organizations [29], [30], [31]. In this stage, the prioritization of the technologies to be developed must be aligned with the demands of the programs, contributing to direct the portfolio towards an application in the products, which represents stage 4 (TRL 7-8-9). Development costs are very high compared to the prospection stage.

In technological development, the prioritization of the technology portfolio is based on budget consolidation, analysis of investment levels, the potential for application in the product, in addition to the study of the maturity level of the proposed technologies and development time.

The relationship between technology push and program pull strategies shows that the approach must be balanced. Most of the time, aerospace technology has been driven by needs identified in programs. Although many programs have taken the risk of pulling on a technology successfully, there are less fortunate examples where an excessively high price has been paid for incorporating technological development. Programs that considered the technology push strategy to allow future missions are referred to as driving opportunities, while technologies driven by program or market demands are called necessary [43].

Throughout the stages of the model, information must be monitored continuously so that strategic actions are initiated, changed, interrupted, or expanded in response to the data, increasing the flexibility of the system (stage 5). Monitoring takes place at the scientific, technological, product, and market levels, involving different degrees of information in areas that may or may not be relevant to the organization. Continuous monitoring can contribute to the evaluation of the use of information to capture opportunities.

The dynamic and adaptive model contributes to the strategic actions of the organization, generating interventions that can speed up the change of route in a path very different from the one initiated. Seizing opportunity, that can drives strategic change, is directly related to ontological uncertainty. It can be induced by the strategy itself in the form of reflexivity or in the unknowns that occur over time [19]. This model can deal with ontological uncertainty since strategic actions can change over time, as new knowledge about future states becomes available [19], [44].

In this way, the decision-maker must continually reevaluate the future possibilities, eliminating and adding options, according to what is implicit in the stock of evidence accumulated by the assessment of each state considered. The evidence of the possibilities of each future considered ensures that futures radically different from the present are taken into account, contradicting the tendency of decision-makers to discard extreme futures based on current data [19].

Discontinuous changes, the time to develop an aerospace technology, ontological uncertainty, and risks demand actions of the organization, both internal and external so that it can identify and take advantage of opportunities in building and balancing its technology portfolio. Internal actions refer to maintaining the qualification of the environment, which depends on its capabilities. And external actions refer to development partnership strategies, through universities, research institutes, and consortia.

VI. Conclusion

This article seeks to expand the concept of generative sensing to generative sensing and seizing (GSS), in a dynamic and adaptive framework. The objective is to improve the confidence level of decision-making processes regarding the selection of technologies under conditions of ontological uncertainty. The origin of ontological uncertainty is the changing nature of reality, resulting from surprises compared to what is currently unknown, and also from cases of reflexive responses stimulated by new developments [19]. The environment of changes and uncertainties favors sensing and seizing but requires quick and flexible actions by organizations.

The model highlights some important points in the selection of the technological portfolio of aerospace organizations:

- Prospection represents the stage of exploration of multiple technologies with low maturity and includes research, laboratory tests, simulations, learning, and capacity development. This stage involves partnerships with universities, research institutes, as well as scientific consortia. Due to the costs, significantly lower than in the later stage, technological development, the decision to proceed, or discontinue the development of some technologies must be in this phase (technological prospection). The budget resources need to be sovereign, without frequent fluctuations, and the project control must be more flexible.
- Depending on the directions suggested by the prospection and the needs of the programs, managers can prioritize, more clearly and confidently, the technologies to be developed. At this stage, costs are much higher, because they include qualified labor, infrastructure, manufacturing, quality control, and certification, among others.

The evaluated projects show that the uncertainties in prioritizing technologies can be minimized with investments in the prospection phase, which, being exploratory, suffers less from the impacts of market volatility.

The model highlights the importance of alignment and collaboration between the stages, as well as a clear vision of the corporate strategy, which can contribute to directing the technological strategy to capture and take advantage of opportunities, favoring a culture that places the organization ahead of competitors in some technologies. In this way, the scientific monitoring group seeks to detect opportunities for the organization (sensing), while the product and market monitoring group focus on market needs and technological gaps. The technology monitoring group makes the connection between the other groups, prioritizing the development of technologies that can be applied to the product (seizing), and thus improving the possibility of return on investments in capacities and technologies.

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