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Portfolios of promise: A review of R&D investment techniques and how they apply to technology development in space agencies

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ABSTRACT

Despite a rich legacy of impressive technological accomplishments, the government acquisition of advanced space systems is increasingly synonymous with schedule slips and cost overruns. Program reviews have suggested that investing more in centralized and strategic research and development outside particular programs will reduce technical uncertainties and improve cost and schedule outcomes. This paper suggests roles for a centralized technology office by examining the methods available in the literature for managing portfolios of research projects.

In particular, the paper answers three questions. Firstly, it examines the key features that characterize the space agencies' innovation context compared to the private sector where most of the portfolio literature is founded. Secondly, it summarizes the advantages and disadvantages of the models in the literature. Finally, the paper addresses how innovation decision making should be structured within agencies in order to achieve the best results. The paper concludes that an executive level technology office is best placed to act as an enabler, rather than an absolute decision maker. Such an office would not replace decision making at the technical manager level, but would provide overall strategic direction and guidance within which technical managers can make decisions about project innovation.

1. Introduction

1.1. Centralized innovation in space agencies is a growing trend

Despite a rich legacy of impressive technological accomplishments, the government acquisition of advanced space systems is increasingly synonymous with schedule slips and cost overruns. Recent examples include the James Webb Space Telescope and the Mars Science Laboratory in the United States and the Galileo navigation satellites in Europe [1]. Repeated examinations by blue-ribbon panels have found that sufficient investment in R&D is a necessary condition for sustained performance and competitiveness [2–10]; however, when faced with constrained budgets, senior leaders struggle to justify highly uncertain investments, which may not pay off for decades [11–13].

One of the organizational responses to the difficulty of investing in innovation has been to centralize funding. Centralization of innovation is part of a wider trend of centralization in search of greater efficiencies, for example centralization of design in the commonality literature [14,15] and centralization of logistics planning in the 'just-in-time' literature [16]. Some of the benefits that can be identified with centralized innovation funding are increased accountability of spending, identification of interdependencies between projects in different areas of the organization and consequent investment in cross-cutting technologies, and better alignment of innovation outcomes with organizational goals. In NASA, this reasoning motivated the creation of, and increased resourcing for, the Office of the Chief Technologist [17]. In ESA, there is a growing trend towards a more formalized and centrally managed technology strategy, for example through the 'technology observatory' program [18]. However, centralization also has drawbacks. It increases the number and complexity of the innovation decisions the central office must make. Centralization also removes decision making from individuals with detailed technical understanding of the projects, posing challenges for information flow through the organization.

1.2. How can space agencies do better in centralized innovation?

This paper seeks to help space agencies to do better in centralized innovation by making sense of the existing literature on investment in innovation portfolios. There is a significant amount

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of literature, mostly arising from industry studies, which presents methods for efficiently selecting where innovation funding should be spent. However, the literature does not translate neatly into the innovation context for space agencies. In order to assess the relevance and usefulness of the innovation portfolio literature to space agencies, this paper examines three specific questions.

Firstly, *what are the key features that characterize the space agencies' innovation context compared to the private sector where most of the models were developed?* Space agencies have challenges not faced by the private sector, including the inability to describe innovation value in simple monetary terms, the need to maintain a specialized industrial base, and the need to achieve several simultaneous innovations to meet organizational goals.

Secondly, *what are the strengths and weaknesses of the methods found in the literature?* The range of methods have evolved in part because no method is applicable to every situation. This has led to a wide variety of available methods, each with their own areas of application.

Finally, given the merits of the methods in the literature, *how should innovation decision making be structured within agencies in order to achieve the best results?* The centralization of innovation funding does not necessitate the centralization of innovation decision making. An executive level technology office can continue to allow decision making on innovation at more technical levels in the organization, using and promoting the use of the most appropriate methods from the literature throughout the organization.

1.3. No innovation decision methods in the literature are tailored for space agency needs

Unsurprisingly, no existing work was identified which examined methods for developing space technology innovation portfolios at the whole-of-agency level. There are however a number of papers which examine the innovation portfolio problem more generally. One set of papers are the pure review papers, which summarize the state of research across the suite of innovation portfolio methods. The most recent of these papers is the work of Heidenberger and Stummer [19], although a large number of reviews were conducted from the 1960s through to the 1980s and many of the techniques used have not changed substantially [20,21]. There are also textbooks which provide a basic review of innovation investment strategies [22]. Other papers review portfolio theory in a more cursory fashion as a preparatory step to proposing new models [23,24].

In the context of space agency innovation, several papers have been written about the application of decision methods to R&D projects at NASA [25,26]. However, these papers do not approach the breadth of projects required to conduct an analysis of NASA's entire basic research portfolio. Attempts in other industries appear to be similarly constrained [23].

As part of the review of methods, the methods captured in this study were compared to the methods captured by other review papers, including those by Heidenberger and Stummer [19], Henriksen and Traynor [23], Danila [20] and Hall and Nauda [27]. This paper covers almost all the methods outlined in those papers, suggesting that most of the methods currently available for planning and assessing innovation are presented.

1.4. Outline of the following sections of this paper

The remainder of this paper is structured in the following way. The first part of the paper provides necessary background to portfolio approaches to innovation and how innovation is applied in space agencies. This introductory material includes a discussion of the advantages of 'portfolio' approaches to innovation decision making over simply selecting the best projects.

The second section of the paper summarizes the literature on innovation portfolios and evaluates the advantages and disadvantages of the different methods in detail. First methods for selecting the best projects are studied (for simplicity we will refer to these as 'project methods'). Project methods are a necessary precursor to the methods for selecting the best portfolios of projects ('portfolio methods'). Many of the portfolio methods use one or more project methods as their core.

Finally, the paper analyses the centralization of innovation decision making in light of the methods available in the literature. The analysis concludes that there are benefits to the existing decentralized system, which risk being lost if the pendulum swings too heavily towards central decision-making and control of research funding.

2. Portfolio approaches to innovation are powerful but challenging to implement

2.1. Portfolio approaches help to measure and manage risk

Portfolios are a powerful concept in managing the funding of innovation. This section of the paper describes why good portfolio approaches mean more than just selecting a group of the best performing projects in the hope that their successes 'average out'.

In general terms, a portfolio consists of a number of different investments, which combine to achieve a goal. In this case, the investments are made by allocating resources to innovation projects and the goal is success for the organization as a whole. Multiple R&D projects must be undertaken as alternative ways of meeting the goals. Failure in some R&D projects or in some end-products must be anticipated and planned for. In moving towards portfolio thinking, the technology manager stops asking *"What is the best project to fund?"*, and instead asks *"What is the best set of projects to fund?"*.

One advantage of portfolio thinking is avoiding all the research eggs sitting in one basket. Certainly, if nothing is known about the projects, then investing in a portfolio of projects, rather than backing a single project, intuitively reduces the risk associated with R&D from the agency's perspective. In statistical terms, investing in a number of identical projects reduces the standard deviation of the returns without reducing the expected return. This is referred to by Linquiti [28] as "naïve diversification." For example, Fig. 1 shows the change in expected return from investing in a single project through to two projects to five projects, all of which perform independently and with the same risk–return profile.

It is important to recognize that none of the scenarios in Fig. 1 is better than the other until the risk preference of the decision maker is taken into account. The single project approach has higher best case returns than the five project portfolio, and therefore may appeal to a decision maker with high levels of risk acceptance. However, long term management of space agencies is usually risk averse because failures can become highly politicized. In a risk-averse environment, diversification has advantages by reducing the likely worst-case returns.

Linquiti called this type of diversification "naïve" because it doesn't harness the real power of portfolios: interdependence. Interdependence is where portfolios move from being a simple averaging-out to being a powerful tool for managing future uncertainties.

The projects in a portfolio are never completely independent. (In statistical terms, dependence means that knowing the outcomes from one project changes the probability distribution of other project outcomes.) There are several causes of this dependence.