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Management analysis for the space industry

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ABSTRACT

The objectives of this study are to review prior research which analyzes the space industry from management perspectives and to show that there is much more scope to analyze it for providing suggestions about management in the industry growth. There are two clusters of prior research, focusing on risk management and technology management. Certain other research themes are dispersed across several fields and do not form clusters. As conclusions, the two suggestions are provided about those fields that require increased research attention in future; first is organizational behavior to improve efficiency of business operations and to get business opportunities, and second is public support for designing appropriate business environments, which facilitate firms to generate new business in the space industry.

Contents

1. Introduction

The space industry has been attractive for researchers from management perspectives in recent years. The foci of prior research in this industry have included political and legal issues, as well as management issues. As the business environment alters due to an increasing number of new entrants, there is a growing demand for analysis from management perspectives. New entrants attack existing firms by providing competitive products at lower prices and supplying new products and services. The objective of this study is to review prior research focusing on the space industry from management perspectives and delineate those fields that require increased research attention in future.

There are two main clusters of prior research, which analyze the space industry from management perspectives: risk management and technology management.

Research on risk management is motivated by identifying the causes of space shuttle accidents, and it aims to provide recommendations in order to avoid accidents; the foci of analysis are organizational systems and decision making processes.

On the other hand, technology management research is driven by changes in research interests following the end of the Cold War; researchers have extended their interests from the inside of the organization, to the outside. The main reasons for the change are that firms in the space industry are forced to manage technology in

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consideration of profitability, as governmental subsidies have decreased and new entrants have appeared. Firms have to secure new sources of funding under tight financial restrictions. Some select technical cooperation with external organizations to save research expenses, and others secure new sources of funding by having external organizations utilize existing technology. Along with changes in organizational behavior, researchers' interests began to be directed toward technology management.

As noted, certain other prior research is not included in the two main clusters but there is not sufficient research activity to demarcate a cluster, or clusters.

The overarching aim is to contribute to future research on management for growing space relevant businesses, and on industry policy pursuant of space industry growth-by delineating issues, which have been insufficiently studied. This study develops logic through the following two steps.

Firstly, this study shows that the transition of source of demand in the space industry has added management perspectives to researchers' interest. There is a peculiar characteristic regarding source of demand in the space industry, which is that the proportion of public demand has been higher than private demand. The high percentage of public demand has depended not only on security but also on business characteristics that a huge investment is necessary to build infrastructures. For example, in the case of a communication satellite, government has created infrastructures including relevant knowledge base on the physical nature and phenomena of space, a set of space system such as launch vehicle, and the institutional framework [1]. However, business environments have changed since the 1970s when the Soviet Union withdrew from the competition with the United States [2]. Public investment in the space industry has decreased. Hall [3] describes that the incentives of innovation at NASA changed from winning the space race with the Soviet Union in 1960s to being technology sources of scientific knowledge for space development. In addition to that, new entrants such as SpaceX have come to focus on another dimension as competitive advantages like price reduction since 2000s. The transition of source of demand brought about a change in research focus.

Secondly, this study shows that there is room to accumulate knowledge about business processes and organizational behavior to harness business opportunities in the space industry. For example, reduction of launch costs and miniaturization of satellites have increased business opportunities utilizing space for private demand in recent years. However, there is a lack of research into analyzing business and management issues in the space industry, excepting technology management. Unless knowledge based on analysis of business processes and organizational behavior accumulates, resource allocation for business development will be inefficient, and policy makers have insufficient information in order to provide optimal public support to the industry growth. Therefore, future research is required to analyze business and management issues in the space industry. Such research could offer suggestions about the location of business opportunities and enable optimal resource allocation for business development and industry growth.

In the next section, prior research on risk management is reviewed. Then, in section three, prior research on technology management is reviewed. In section four, prior research about other factors, which influence business performance, is reviewed. In the final section, this study concludes that future research is required to accumulate knowledge of analysis about business processes and organizational behavior from management perspectives.

2. Risk management

Risk management has been one of the main issues in prior research since the space shuttle accidents. The focus of research is placed on the reasons why the accidents happened, and the objective is to give suggestions about management for building an organizational system designed to avoid future accidents. Prior research points out two causes of organizational failure which led to the accidents. First is project structure, which makes information sharing difficult, and second is complex decision making processes under political pressure and time constraints.

Table 1 lists major research in the risk management domain. Firstly, Vaughan [4] and Carroll et al. [5] analyze project structure for launching the space shuttle and regard causes of the accidents as project structure, which makes information sharing difficult. Vaughan (1988) focuses on the Space Shuttle Challenger accident and analyzes regulating systems for safety at NASA. Carroll et al. [5] analyze project processes of organizational redesign at NASA.

Vaughan [4] analyzes official documents gathered by the Presidential Commission on the Space Shuttle Challenger Accident. Data for analysis is collected by interviews with organizational members who are responsible for regulating system for safety at NASA and journalists who investigated NASA's safety system. The conclusion is that the Challenger accident was caused by the regulating system for safety, which failed to identify technology problems. The reason the regulating system missed critical problems is that it lacks an appropriate mechanism for sharing information about technology problems. There are three units internal to NASA and external contractors, which are involved in regulating system for safety. Internal units and external contractors are in a difficult position to point out technology problems. As the internal units are interdependent with members who cause technology problems, it is difficult for them to objectively and strictly point out their problems. On the other hand, as external contractors are autonomous organizations that are independent from NASA, it is difficult for them to obtain information, which is detailed enough to recognize technology problems. Therefore, both organizational interdependence and dependence obscure technology problems, which are causes of space shuttle accidents.

Carroll et al. [5] focus on project processes of organizational redesign, which were carried out at NASA after the Columbia

Table 1
Major prior research in the risk management domain.

Category	Literature	Sample	Main conclusions
Risk management	Vaughan [4]	The space shuttle accidents.	Both autonomous and interdependence of relevant organizations obscure effective regulation of causes of accidents at NASA.
	Carroll et al. [5]	The space shuttle accidents.	The misfit between organization design and task environment causes the space shuttle accidents.
	Hall [3]	The space shuttle accidents.	Reducing budgets causes shortage of management resources, which makes it difficult for engineers to solve problems carefully.
	Feldman [6]	The space shuttle accidents.	Emphasis on objective data causes overconfidence in quantitative data and ignorance of qualitative data, leading to overlook the root cause of problems causing accidents.

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accident. NASA faces a dilemma in redesigning organization structure. The dilemma is caused by a contradiction between pursuing less communication system for geographically dispersed centers and requiring frequent communication for integrating a large number of systems for the space shuttle. They suggested that the misfit between organization structure and task environment caused the Columbia accident. The challenge is to manage and coordinate distributed engineers for launching the space shuttle. Prior research such as contingency theory suggests the importance of fit between organizational structure and task environment. However, it does not provide satisfactory solutions for the case of their misfit. Although matrix organization is one of the options available to solve the contradiction, the complexity makes it difficult to carry out the project under time constraints. NASA finally designs a team which is chartered to perform both technology and system tasks through design, development, testing, and evaluation.

On the other hand, Hall [3] and Feldman [6] focus on management failure to recognize problems as causes of the accidents at NASA. Their sample is also the space shuttle accidents. They propose solutions for decision making processes in order to reduce the risk of accidents.

Hall [3] points out that decision making based on past knowledge is the cause of space shuttle accidents. According to Hall [3], emphasis on past knowledge is due to shortages of management resources. Human spaceflights occur based on less budget than before; the budget for NASA was cut after technological competition with the Soviet Union came to an end. Reducing budgets causes a shortage of management resources, thus sufficient resources are not allocated for problem solutions. In other words, a shortage of management resources makes it difficult for engineers to solve problems carefully, and decision making becomes path dependent based on past knowledge. This causes misunderstanding of the root causes of problems. Hall [3] concludes that a flattened hierarchy and collaboration with external contractors may be effective for error detection and correction. This would give opportunities for engineers to express opinions without being caught up with past knowledge.

Sauser, Reilly, and Shenhar [7] also support the notion that less management resources causes accidents at NASA. They show that the Mars climate orbiter loss at NASA, which is the accident where the spacecraft signal was lost in 4 min after arrival on Mars, was caused by time and cost pressures making it difficult for organizational members to retest some systems.

Moreover, Feldman [6] analyzes decision making at NASA in the years preceding the explosion of the space shuttles. The conclusion shows that the accident was caused by culture that emphasizes objectivity at NASA. Engineers recognize problems based on objective data and explore solutions within their own expertise. This results in overconfidence in quantitative data and ignorance of qualitative data, leading to overlook the root cause of problems causing accidents. Their motivation for problem solutions are not always in line with the organizational goal of achieving safe launch and return of space shuttles.

Prior research is in agreement with the view that space shuttle accidents are caused by failures in organization systems; organization systems lack a mechanism that recognizes the root cause of problems. The reasons why there is not such a mechanism at NASA are communication problems, misfit between organizational structure and task environment, complex decision making processes, and emphasis on past knowledge and objectivity of data. These reasons hinder the pursuit of the organizational goal of safe operations for launching space shuttles.

3. Technology management

There is another extant research cluster focusing on technology management in management analysis for the space industry. Table 2 lists major research in the technology management domain. Prior research has concerned itself with the effectiveness of two ways for using external knowledge at the firm level to generate new business: technology collaboration with external organizations and open innovation.

3.1. Technology collaboration

Technology collaboration with external organizations enables firms to gain access to new knowledge. In the space industry, the spillover of technical knowledge is not unusual. Products supplied for the space industry are highly complex, and product development needs technology collaboration with external organizations to avail of technical knowledge not within organizations [8]. Jaffe, Fogarty, and Banks [8] analyze patent citations of US government based on a random sample of all US inventors between 1963 and 1994, and case studies at NASA. Although they conclude that patent

Table 2
Major prior research in the technology management domain.

Category		Literature	Sample	Main conclusions
Technology management	Technology collaboration	Jaffe, Fogarty, and Banks [8]	Patent citations. Case studies at NASA.	Patent citations are a valid but noisy measure of technology spillover. Two-thirds of patent citations are regarded as spillover.
		Kratzer, Gemünden, and Lettl [10]	Joint product development of telescopes.	Misalignment between formal and informal communication flow influences project efficiency negatively, and creativity positively.
		Fernandez, Anne-Sophie, Le Roy, and Gnyawali [11]	Joint product development of telecommunications satellites by Astrium and TAS.	Ordering parties such as ESA and project managers contribute to easing inter-organization and intra-organization tensions.
	Open innovation	Culbertson [13]	NASA's Technology Utilization Program.	Technology transfer from the public to the private sector is hindered by differences in organizational objectives.
		Petroni, Verbano, Bigliardi, and Calati [15]	Eight successful technology transfer projects at six large space agencies including ESA and CNES.	Technology versatility and reliability are the most influential factors on technology transfer.
		Senghore, Enrique, Pavel, and Wasek [16]	International Space Apps Challenge at NASA.	Competition in a network drives innovation, and co-location and network vitality do not influence the generation of innovation.
		Davis, Richard, and Keeton [17]	Open innovation in HH&P at NASA.	HH&P adopts a system to solve problems by using external knowledge following budget reduction.

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citations are a valid, but noisy measure of technology spillover, their case studies show that two-thirds of patent citations are regarded as spillover.

In the case of technology collaboration among countries, security in addition to technical complementarity is a subject to be considered. Zervos and Siegel [9] analyze a case study of a product development project for the Galileo space-based system navigation, which includes public and private organizations from different countries. They conclude that a cause of the failure of the transatlantic partnership for that system was not only industry competition but also security concerns.

However, there is limited extant research which discusses security issues based on management perspectives. Where that research does exist, it focuses mostly on factors which influence the performance of technology collaboration.

Kratzer, Gemünden, and Lettl [10] analyze two joint ventures focusing on the development of telescopes for the space industry. They find that there is misalignment between formal organizational structures and informal communication networks. This is because the informal communication network is stable, even though the formal organizational structure changes in the transition of product development phases from design through to integration. Informal communication networks across organizations depend on factors such as community specialization. Misalignment between formal organizational structures and informal communication networks influences project efficiency and creativity differently. It negatively correlates with efficiency at both the design and integration phases. However, creativity is an inverse U-function of misalignment and is thus at its highest at moderate misalignment. Their findings show that it is necessary to design an optimal communication flow according to the objective of the project.

Fernandez, Anne-Sophie, Le Roy, and Gnyawali [11] also focus on joint product development in the space industry. The sample is a joint development venture focusing on telecommunications satellites by Astrium and Thales Alenia Space (TAS). They analyze inter-organizational and intra-organizational tensions and provide suggestions about management to reduce the tensions. They find that there are two factors which reduce the tensions. The first factor is an organization which orders telecommunications satellites: it has an incentive to arbitrate manufactures for achievement of mission and to reduce their tensions. The second factor is project managers: they contribute to reducing tensions by encouraging information sharing.

Technology collaboration is an important option for organizations that develop complex products. However, there is still room for further research into factors and mechanisms, which influence the performance of technology collaboration. The next section reviews prior research on open innovation, which is also a principal concern of technology management studies in the space industry.

3.2. Open innovation

Open innovation is an organizational system to excavate the value of existing technology by using external knowledge [12]. It is not a new system in the space industry. Culbertson [13] analyzed a similar system at NASA in the 1960s. Culbertson [13] focuses on NASA's Technology Utilization Program, which is a program to promote technology transfer from NASA to external organization. He finds that technology transfer is not functioning well and explains the reason in terms of differences in organizational objectives. NASA has a mission of space exploration and exploitation, and technologies developed for missions are not expected to be used in the private sector. Reliability and functionality of technology is bespoke to space. This is because firms face difficulties in finding business opportunities for the application of NASA's technology.

Petroni and Verbano [14] focus on technology transfer in the context of the Italian Space Agency (ASI). The objective of promoting technology transfer is to grow small and medium-sized firms in Italian technology and science parks. ASI shows technologies which are available to external organizations and gives sessions of supplementary explanations about those technologies for organizations, which have interest in adopting space technologies. In Italy, the technology transfer system is encouraged by the government and contributes to industry growth [14]. Therefore, in order to ensure technology transfer works well, the support system of the technology supplier side is important.

Petroni, Verbano, Bigliardi, and Calati [15] find that the performance of technology transfer depends on technology type. They analyze the mechanisms of technology transfer in the space industry through five years of field research. The sample is eight successful technology transfer operations at six large space agencies including European Space Agency (ESA) and Center National D'études Spatiales (CNES). They conclude that versatility and reliability are the most influential factors affecting technology transfer. Versatility means the easiness of application to other industries. Versatile and reliable technologies are transferred more often than technologies which do not have such characteristics.

Open innovation does not only concern transfer technology, but it also embodies the utilization of external knowledge to develop new business.

For example, NASA opens their data to promote innovation which is relevant to the space domain. It has been holding regular meetings where participants resolve international issues with open data. Senghore, Enrique, Pavel, and Wasek [16] analyze this challenge in order to understand the derivers of innovation. They find factors which are positive and negative influence for driving innovation. Positive factors include competition in a network, and negative factors are co-location and network vitality which is measured in terms of numbers of projects in each location. Their finding suggest that creating a mechanism whereby participants compete with each other may increase the effectiveness of open data.

Also, Davis, Richard, and Keeton [17] show that budget reduction at the Human Health and Performance (HH&P) Center at NASA stimulates organizational members to adopt open innovation processes, though there is organizational resistance to start it. The mission of HH&P is to maintain health and productivity of astronauts in space. Even after budget reductions, there is no change in the mission. Therefore, HH&P adopts a system to use external knowledge in order to mitigate issues caused by funding cuts.

Open innovation has gained more attention in the space industry from researchers in recent years. This is because public investment in research and development in the space industry has decreased since the end of the Cold War. It is an attractive option for organizations to save costs. Chesbrough [12] suggests that firms should cooperate with external organizations in order to save development costs. Also, he shows that there is another source of profit in obtaining royalties by having external organizations use internal technology [12]. Prior research supports Chesbrough [12]. They show that public research institutes face significant reductions in financial support from government, and they start to search for opportunities to commercialize their technologies through open innovation.

4. Other management factors

Two main clusters in extant research are risk management, which analyzes the organizational causes of accidents in NASA and technology management, which analyzes organization systems for external knowledge use. Certain other prior research analyzes the space industry from different management perspectives.

Table 3 lists major research into other management factors. In terms of units of analysis, three levels can be identified in prior research: an industry, an organization, and a project. Where the unit of analysis is an industry, Zervos [18] analyzes the reasons why competitive procurement has become difficult in recent years. Broekel and Boschma [19] analyze the characteristics of knowledge networks in the space industry under comparison with the aviation industry. At the organizational level, Maxwell, Van Wassenhove, and Dutta [20] analyze organizational factors, which influence the productivity of software development projects. Berente, Lyytinen, Yoo, and King [21] analyze the relationship between management of routines and organizational efficiency. Finally, where the unit of analysis is a project, Archibald and Finifter [22] analyze a tradeoff in resource allocation between business development and basic research. Kratzer, Leenders, and Van Engelen [23] analyze the role of the project leader in influencing a team's creativity with respect to engineering designs.

Firstly in terms of industry analysis, Zervos [18] finds that high market concentration has hindered competitive procurement policy at NASA since the mid-1990s. Market concentration in the space industry becomes high by merger and acquisition of suppliers justified in terms of pursuing economies of scale. In other words, a cause of organizational integration is diminishing government budgets for the space industry following the end of the Cold War. They integrate their organizational operations to save costs. The decreasing number of suppliers has made it difficult for NASA to carry out procurement at competitive prices.

On the other hand, Broekel and Boschma [19] analyze knowledge networks of the space industry in the Netherlands. They compare knowledge networks between the aviation industry and the space industry, which are often aggregated as the aerospace industry. There is a lack of direct ties between the two industries, which are connected by non-profit organizations. Broekel and Boschma [19] find that the space industry has science-based analytical knowledge and a higher density knowledge network than the aviation industry. Also, they point out that research institutions in the space industry provide firms with access to demand, which comes primarily from government.

Secondly, in terms of management for improving performance at the organizational level, Maxwell, Van Wassenhove, and Dutta [20] focus on software development projects and identify organizational factors, which influence productivity. They analyze the ESA dataset, which is comprised of 108 software development projects of 37 firms in eight European countries. They conclude that size of the project team, languages for programming, application category, use of modern programming practices or software tools, software reliability requirements, and main storage constraints influence productivity at the project level and that languages for programming and start year of projects influence productivity at the organizational level.

Berente, Lyytinen, Yoo, and King [21] focus on the relationship between the management of routines and organizational efficiency. The sample is the process of enterprise resource planning (ERP) implementation at NASA. They define organizational routines in terms of three aspects: ostensive, material, and performative. Ostensive means individual conceptualization of routines, material means technology features of routine enactment, and performative means enacted routines. If these three aspects are not in alignment, organizational efficiency decreases. The relationship among these three aspects of routines fluctuates due to ERP implementation. Berente, Lyytinen, Yoo, and King [21] suggest that adjusting fluctuations for alignment improves organizational efficiency.

Finally, as contemporary researchers have stronger interest in business performance compared to before, they pay attention to projects which influence organizational business performance in addition to the organization as a unit of analysis.

Archibald and Finifter [22] point out a tradeoff in resource allocation between business development and basic research. They analyze projects which are selected for the Small Business Innovation Research (SBIR) program and financed by the NASA Langley Research Center. SBIR is a program to increase investment in research, which has potential for commercialization. Their conclusion is that SBIR contributes to selecting more commercially successful research but reduces opportunities for conducting basic research.

Kratzer, Leenders, and Van Engelen [23] examine empirically the role of the project leader in influencing team's creativity based on a sample of 39 engineering designs in the space industry. They analyze the network position of a project leader in communication flow. The conclusion is that a project leader should maintain moderate involvement in the internal communication network and focus on the role of gatekeeper to gain useful information from external organizations.

The object of analysis in prior research has changed particularly since the Cold War has ended, and the transition shows that researchers have diversified their interests in the space industry. The diversification is particularly toward management for improving business performance. This is because organizational environments have changed; business opportunities have increased in private

Table 3
Major prior research into other management factors.

Category	Literature	Sample	Main conclusions
Other management factors	Zervos [18]	Procurement processes at NASA.	Market concentration has hindered competitive procurement policy at NASA since the mid-1990s.
	Broekel and Boschma [19]	Comparison of knowledge networks of the space and aviation industries in The Netherlands.	The space industry has a higher density knowledge network than the aviation industry and science-based analytical knowledge.
	Maxwell, Van Wassenhove, and Dutta [20]	ESA dataset comprised of 108 software development projects of 37 firms in eight European countries.	They found factors which influenced the productivity of the organization and project team.
	Berente, Lyytinen, Yoo, and King [21]	The process of ERP implementation at NASA.	Adjusting three aspects of organizational routines for alignment improves organizational efficiency.
	Archibald and Finifter [22]	Projects selected for SBIR.	SBIR enhances the rate of commercial success of projects but reduces the opportunities of basic research.
	Kratzer, Leenders, and Van Engelen [23]	39 engineering designs.	Project leaders should maintain moderate involvement in internal communication networks and concentrate on the role of gatekeepers to gain useful information from external organizations.

markets. There is room for future research to provide answers about how firms should respond to changes in the business environment. The next section suggests fields that require greater research attention in future.

5. Conclusions

The tables in each section show that research interests related to management perspectives in the space industry have shifted from organizational systems for risk avoidance to technology management and other factors for improving business performance. However, there are still ample room to analyze the business environment in the space industry. Prior research does not provide sufficient suggestions vis-à-vis optimal business models and public support aimed to facilitate industry growth.

In the space industry, the source of demand influences incentives of organizations for innovation. The high percentage of public demand enables them to pursue cutting edge innovations in product development without intense competition. Firms can afford to develop high value added products with cutting edge knowledge to meet public demand. Researchers have focused on maintaining employment in the space industry and making operations more efficient rather than how to make profits and develop new business. For example, Holman and Konkel [24] focus on the influence of the Manned Space Flight (MSF) program at NASA on employment in Los Angeles. They conclude that MSF contributed to more than 20% employment growth between 1960 and 1965.

Some changes in the space industry make researchers pay attention to management perspectives. The changes are increasing cost constraints and private demand. First, as has been described repeatedly in previous research, public financial support for the space industry has been decreasing since the Cold War ended. Next, private demands for services with satellites are growing by lowering prices of rocket launch services, though public demand still drives market growth. Zervos and Siegel [9] point out that partnerships between public and private organizations in the space industry increased to enhance profitability and reduce costs in 1990s after the end of the Cold War. Also, Maryniak [25] describes that existing firms struggle in the face of severe price competition from new entrants to capture private demand, because they have high technology capabilities but weak cost concerns. Therefore, the demand for management perspectives has risen in the space industry. As cost constraints strengthen, firms recognize the need to streamline business processes. As private markets expand, they have come to recognize the need to develop strategies that can acquire more business opportunities.

As conclusions, the following two suggestions are provided for researchers who have interests in analysis of the space industry from management perspectives.

Firstly, there are still room to accumulate knowledge about organizational behavior to improve efficiency of business operations and to capture business opportunities in the space industry. Researchers have to clarify the flow of supply chain processes, to show locations of business opportunities in the flow, and to explore the appropriate strategy for each business opportunity. Their efforts may contribute to industry growth, because firms are able to find business opportunities and to allocate their management resources to develop new business more efficiently than without the knowledge.

Secondly, researchers may be able to accumulate knowledge for designing appropriate business environments, which facilitate firms to generate new business in the space industry. Appropriate public support for new business development promotes new entrants and builds healthy competition among firms. Innovation generated as a result of the competition may drive industry growth.

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The author discloses any actual or potential conflict of interest including any financial, personal or other relationships with other people or organizations within three years of beginning the submitted work that could inappropriately influence, or be perceived to influence, the work.

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