TOULOUSE BUSINESS SCHOOL
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Space Debris Removal as an Effective Business Model - Challenges and Opportunities

Research paper

Eniko MOLNAR

Stella VIRVE

Supervisor: Victor DOS SANTOS PAULINO

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ABSTRACT

People around the world are strongly dependent on the systems created in the space. These include different applications covering navigation, intelligence gathering, reconnaissance, surveillance and other connected national security activities, creating the ecosystem for the constant well-being of global economy and international security. This reliance is however confronted with the increasing amount of debris in the space, which incorporates several risks and calls for the attention to the active removal processes. Undertaking space debris removal activity invites to debate about the effectiveness of this operation, especially in business terms, as it requires different applications that conventional companies do not confront. Consequently, the focus of this research paper is to understand and assess whether the activity of space debris removal is an effective business model. In order to investigate the issue, exploratory approach is performed with the external secondary research method. The results show that several opportunities exists for different parties of interest in order to benefit from the space debris removal. Nevertheless, there are numerous challenges, and on the bases of the business model, the overall consideration evaluates this activity as not effective. The technological answers and innovation processes are still in the development phase, therefore it can be stated that there is room for improvement in terms of increasing the effectiveness in business terms and alter the current adverse consideration.

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SPACE DEBRIS REMOVAL AS AN EFFECTIVE BUSINESS MODEL - CHALLENGES AND OPPORTUNITIES

Nowadays, space holds an important role in the human operations. The world is dependent on the systems created in space and the infrastructure that is contributing to the navigation, intelligence gathering, reconnaissance, surveillance and other connected national security activities (McCormick, 2013, p. 801). Our dependency on space for the constant well-being of global economy as well as international security forms the reason of importance to address space debris issue. (*Ibid*. p. 801)

Currently, there are more than half a million pieces of debris traveling in the space. (Garcia, 2013). Nishida *et al.* (2009, p. 277) have highlighted that the quantity of debris in low-Earth orbit (LEO) has provoked a situation where *"the environment has reached a point where collisions among existing debris will result in the population to increase, even without any new launches."* This phenomenon is also known as the Kessler syndrome. Therefore, it is essential to understand the necessity to act and put a large focus on the elimination of space junk. However, undertaking this sort of activity is raising discussions on the topic of effectiveness, especially in business terms, as debris removal requires different applications that conventional companies do not confront. Thus, the research question raised in this paper is following: To what extent does space debris removal activity represent an effective business model? In order to investigate the issue, supporting questions are developed:

- What are the underpinnings of the business model concept?
- How is the effectiveness measured?
- What is space debris and how are the active removal methods implemented?
- What are the possible challenges confronting the development of space debris removal business model regarding existing technologies?
- Which opportunities emerge with the current space debris removal technologies?

The implemented methodology has an explorative approach and external secondary research is performed. The authors will examine previously gathered information in the form of prior studies and researches, articles and other available online sources. This methodology is chosen based on the interest of the topic and research question under consideration as well as taking into account the occurring limitations. The topic of space debris and the necessity of its removal has been discussed for a long time. However, the concept of creating the value of this activity through business and measuring its effectiveness with the support of the business model framework is relatively novel and not thoroughly researched. Consequently, several limitations occurred during the research process, such as the time constraint for conducting in-depth expert interviews, the restriction for the volume of the paper as well as the limited accessibility to the valid and available data, which were not free of charge for public use or simply confidential.

1. THE CONCEPT OF BUSINESS MODEL

1.1 Theoretical framework of business model theory

This sub-chapter will introduce the theory of the business model concept and the most remarkable underpinnings.

The elements that can be related to the business model concept are studied broadly by Porter. Hedman and Kalling (2003, p. 51) highlight Porter's retrieval of encompassing in the model both resource-based view and industrial organizational perspective. Resource-based view is the foundation for the competitive advantage of a company, whereas the concept of the resources can be tackled either as a matter of economically-rational use of resources or as a matter of objectives having resources as means (Müller-Christ, 2011, p. 167). Those resources can represent both tangible and intangible assets. Frieling (2001, cited Müller-Christ, 2011, p. 167) has mentioned input factors that can turn into business-specific factors for the competitiveness, in case the value is added in these input factors and if the availability to use the resources are excluded for the competitors. This signifies the transformation of the input factors into resources which in turn is transformed into competitive advantage.

Competitiveness, however, abducts the resource focus and becomes a matter of power. (*Ibid.* p. 167) Also, industrial organizational perspective which marks the second part of Porter's model, embodies the viewpoint of markets and the structure of business. Tirole (1988, p. 4) has pointed out two-sided approach: firstly, the market strategy and internal organization management; secondly, the assessment of market efficiency (as improbable increase of social welfare with imperfectly competitive markets).

1.2 Business model components

In addition to Porter, Normann (Hedman & Kalling, 2003, p. 51) has studied the concept and describes the model in three separate components. Citing *(Ibid*. p. 51): "*(1) the external environment, its needs and what it is valuing; (2) the offering of the company; and (3) internal factors such as organization structure, resources, knowledge and capabilities, systems, values. The concept is systemic in nature and the relation to the* *external environment depends on the offering, which in turn is dependent upon firm-internal factors."*

The interrelations between different factors in business model have been highlighted as well by Chesbrough and Rosenbloom (see Figure 1). There are complex proportions between the markets, the environment as well as the products that are related to any company's activity. Technical inputs incorporate the elements in the domain of technical expertise and the economic outputs represent the area, where the knowledge of business experts is available. (Chesbrough, & Rosenbloom, 2002, p. 532)

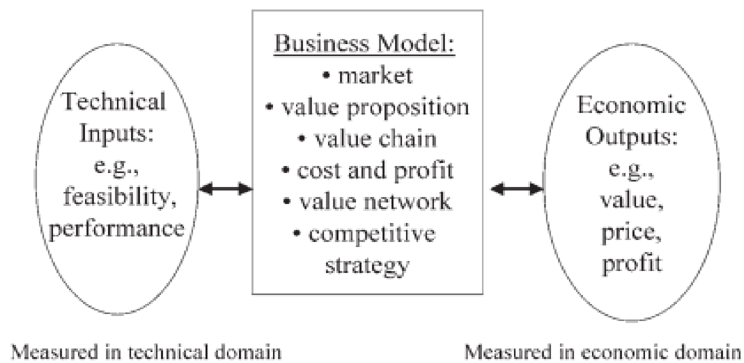

Figure 1. The business model mediates between the technical and economic domain. (Chesbrough, & Rosenbloom, 2002, p. 536)

As displayed above, business model involves numerous distinctive business subjects that are connected to one another, such as economics, marketing, finance, strategy, operations and entrepreneurship. The six elements introduced in the Figure 1, are explained as following (*Ibid.* p. 533-534):

- **Value proposition** - the value created for customers, considering the customer problem, the product that is communicating this issue, and the value from the perspective of the customer.
- **Market segment** - the target group of users, to who the product is useful and for what purpose, specifying the revenue generation mechanisms for the company.
- **Value chain structure** - the position of the company on the basis of the value chain, and to determine the ways of how the company is creating the value.

- **Cost structure and profit potential** - to understand the cost structure, margins and how the profit is generated given the value proposition and the value chain.
- **Value network** - to understand the competitors, complementors that can bring value to the customers within the value chain.
- **Competitive strategy** - the strategy of getting and sustaining advantage over rivals.

It can be noticed that financial dimensions are not included in the model (see Figure 1). This is due to the assumption that *“the model is assumed to be financed out of internal corporate resources, so that financing issues do not figure prominently in the business model; or the model of a startup is to be financed through early stage venture capital.”*(Chesbrough, & Rosenbloom, 2002, p. 535) However, the authors do emphasize that the capability to transmit the created value in the company into to value for the shareholders is demanding the availability of financial resources.

1.3 Measurement of business effectiveness

The following sub-chapter will introduce the business performance measurement underpinnings and introduce some of the commonly used indicators for effectiveness observation.

Venkatraman and Ramanujam, (1986, p. 803) have noted three different approaches in business performance measurement: financial performance, financial and operational performance, and organizational effectiveness. In order to measure the business effectiveness, one needs to understand which business element is under consideration (financial performance, marketing, management, human resources etc). Thereupon, the indicators for measurement have to be appropriate. In this paper, the focus is placed in the overall business performance effectiveness, therefore certain indicators will be excluded, e.g. intraorganizational human resource aspects and comprehensive financial performance analysis. Neely (2002, p. 17) introduces several possible indicators for business performance measurement that are following:

- Short-term profitability;

- Market share;
- Productivity;
- Product leadership;
- Personnel development;
- Employee attitudes;
- Public responsibility;
- Balance between short-range objectives and and long-range goals.

The abovementioned indicators are not firm, as the performance parameters vary from different companies, taken into consideration their key activities. Therefore, some of the elements are not implemented in the discussion part in this paper, as space industry and debris removal is very specific in terms of operations in the business field.

2. SPACE DEBRIS REMOVAL AND ITS DEVELOPMENT PROCESS

2.1 Sources of space debris

In 1957 history changed when the Soviet Union launched successfully Sputnik I, and mankind began its journey to space. It inspired more and more launches in the last six decades leading to serious problems above the Earth's atmosphere. Although we prefer to remember the successful stories, many launches failed leaving large chunks of metal in the space. The upper parts of launch vehicles, discarded bits left over from separation and even tiny flecks of paint all remain in orbit. (Redd, 2013)

Space debris can be natural or artificial. The natural meteoroids are in orbit about the sun, while artificial debris (commonly referred as orbital debris) is in orbit about the Earth, which no longer serves any function. (NASA, 2013) When objects collide, they create thousands of orbiting fragments. Experts now talk about the collisional cascading effect (also called the Kessler effect) in which the density of objects in LEO is high enough that each collision increases the likelihood of further collision. (Byrd, 2013)

2.2 Observation and tracking

Space object tracking is a process, which includes identifying and cataloging the present and anticipated orbital paths of space objects, satellite attack warning also providing avoidance maneuvers to potential collisions. Tracking requires more complex calculations than just simple observation. The Space Surveillance Network (SSN) is the world's largest surveillance system operated by U.S. military, which tracks space objects. (Ansdell, 2010)

According to NASA (2013), there are more than 20,000 pieces of debris larger than a softball (10 centimeters), 500,000 pieces are in the size of a marble (1 centimeter) and many millions so small that they cannot be tracked. As they all travel 17,500 miles per hour, they increase the danger to all satellites, especially to the ISS and space crafts with humans aboard. They damage one satellite each year on average, but the number of collision is predicted to triple by 2030. (David, 2011) The biggest risk comes from the non-trackable debris.

Given the huge number of space fragmentation, there have been surprisingly few direful collisions. In 1996, a French satellite was damaged by a debris from a French rocket. In 2007, China's anti-satellite test used a missile to destroy an old weather satellite, added more than 3,000 pieces of debris right in the most congested region of LEO satellites. This single event increased the number of debris roughly 25 percent. In 2009, a non-functioning Russian satellite destroyed a functioning U.S. Iridium satellite. (NASA, 2013) As a result of these events, and the continuous satellite launches, the altitude from 700 km to 1,300 km has accumulated millions of debris. If we want to use these orbits without any significant changes, the density of debris will definitely grow and more collisions will occur. What could be the possible solutions?

2.3 Cleaning up the space

Cleaning up the space sounds obvious, but making it real is not so simple. There are two ways to reduce space debris: mitigation and removal. Mitigation is about minimizing the new debris production, while removal requires a human-made system or atmospheric drag. Although mitigation seems a simple and cheap solution, experts say it is insufficient, and removal will require complex and expensive technologies. (Ansdell, 2010)

2.3.1 Mitigation and the basic steps

Since 1988, the official policy of the U.S. aimed mitigation. NASA has requirements governing the operation of spacecraft and upper rocket stage, which most of the federal agencies accept and follow in order to prevent the growth of space debris. The U.S. pursues to avoid future collisions in the space, therefore the U.S. Strategic Command has executed Space Situational Awareness agreements with satellite owners and operators. It enables the agency to identify, track and catalog objects in the outer space. The U.S. is also reaching out to all space-faring nations to ensure government and private sector has the needed information. In addition, the U.S. is involved in creating bilateral "Space Security Dialogues" to help prevent mistrust in space, therefore they create best practice guidelines, conduct experiments and provide prior notification of launches. (Hildreth, 2014)

Many experts say, we need to take further steps, or the growth of future debris will be worse than predicted. The 25-year rule is a defense against it. It is related to post-mission disposal, demanding that all nations should launch object into the space, whose lifetime do not exceed 25 years.

In addition, a voluntary effort, an international code of conduct for space has been created by the EU including policies on space debris mitigation. The U.S. initiated consultations with the EU to create a non-legally binding International Code of Conduct. Although the agreement does not force legal obligations, it can be considered as the first step towards an international agreement. The U.S. also offered to consider other proposals and concepts, but they did not get other proposals which met the criteria. (Hildreth, 2014)

2.3.2 Implementation of space debris removal

In order to eliminate the waste in the space, several different methods have been developed. This chapter aims to give an overview of various techniques implemented for active removal of debris in the space.

Nishida *et al.* (2009, p. 278) point out the findings of previously conducted studies where it is indicated that *"at least five to ten large objects should be removed per year"* and "*because the natural orbital decay of defunct objects alone will not be sufficient, active debris removal (ADR) has to be used."* There are both passive and active methods to perform debris removal (*Ibid.* 278):

1) To hook up to a passive target with a leash by net or harpoon *(passive method)*;
2) With an electrodynamic tether that induces a Lorenz force by interacting with the Earth's magnetic field *(passive method)*;
3) Pulling with a dedicated propulsion unit or actual spacecraft and remove the target from orbit such that it will enter the atmosphere *(active method)*;
4) Encountering an active chaser spacecraft with the target, span to it, and use the chaser's propulsion system to force the combination *(active method)*.

In order to implement either passive or active removal methods, appropriate technology has to be used, which is very specific in this field.

2.3.3 Active debris removal

Although mitigation is necessary, as mentioned earlier, it is no longer sufficient. Active debris removal (ADR) should be developed to stabilize the environment for future generations. According to NASA's simulations, if in the next 100 years five large space objects can be removed, the environment can be stabilized in 200 years. These large objects have masses of 1,000 to 3,000 kilograms. The simulations assume there will be no more collisions, the 25-year rule reach 90% level and future launches keep the NASA's mitigation guidelines. But, if these conditions are not satisfied, more debris will need to be removed. (Hildreth, 2014) The study points out the threat can be reduced significantly and become more manageable by a small group of nations. We can assume that China, U.S and Russia will be among them.

DARPA's Catcher's Mitt study focused on the technological challenges of the ADR. The central finding was that although the small debris causes the greatest threat, no technology can effectively remove, therefore, the ADR should focus on large objects. The study found that proximity operations and advanced grappling techniques are required to remove large objects. Various methods include capturing large space junk by a net, harpoon, lasso, electrostatic blanket attached to an active thrust device or using natural forces found in space environment. (Hildreth, 2014)

Another radical solution might be to stop using the current orbits and replace them with new infrastructure of small satellites placed below 600 km. Estimates say, the situation will not get unstable soon, we would have enough time (20-40 years) to create new constellations, but it would not solve the problem in the long-term. (David, 2011)

2.4 Legal aspects

The National Space Policy limits the debris mitigation process to research and development of technologies, no actual ADR can be done. It is important that there is no international consensus on the definition of space debris. The most cited legislation in connection with it is Article VII of the 1967 Outer Space Treaty. It acknowledges that space objects belong to the country which has launched them. No other country has the right to control or remove them even if they no longer serve any function. Moreover, successfully approaching an object necessitates a detailed knowledge of the object. Therefore, confidential technological information exchange might be needed in some debris removal actions, which requires negotiation of licensing and nondisclosure agreements within the parties.

Another problem arise from the question of liabilities. Currently, the law of spacecraft damages is in the Liability Convention. It declares, each state is responsible of the damages caused by their space objects on the Earth's surface. However, when they cause a damage in the outer space, they are liable if negligence can be proved, which leads to extremely difficult cases. (Hildreth, 2014) These issues demonstrate, even if there would be a mutual agreement of the necessity of ADR, the legal, political and economic conditions are not established yet.

2.5 Possibilities of leadership

Developing space debris removal systems can take decades, through international cooperation. Building the ISS was a similar issue in the past. It also took two decades due to political, technical setbacks, cost more times as previously planned, but at the end it was built. Given the need to start ADR sooner rather than later, one country might take a leadership role. This would accelerate demonstration and build-up trust. (Ansdell, 2010)

As previously described, removing about five (or a few more in case of changes in the conditions) large space debris can significantly contribute in the stabilization of the LEO environment. As the U.S. is responsible for creating much debris, it is a candidate to take leadership position in the removal process. Given the large number of the U.S. satellites, the country is more dependent than other entities. For example, the GPS satellites are key components for the U.S. to stay a globally dominant military power, while war can also become cheaper and faster with better technology. The U.S. government should engage the commercial sector creating a competitive environment and cost minimization. Special funds should be established at the expense of parties who generate debris including satellite manufacturers, operators and service providers. Additional funding could come from service fees. Although leadership position carries many risks, doing so, the U.S. could protect its satellite technology which is vital to remain a military power and day-to-day operations of global economy. (Ansdell, 2010)

3. DISCUSSION

3.1 Arising challenges in space debris removal

In this chapter an effort to discuss the challenges that emerge with the current space debris removal, is made.

Small debris (0 to10 cm) collection causes the biggest challenge, as we cannot track them all or collect, yet they can cause serious harm. The large debris collection (from 10 cm to 1 m) can be tracked, and the even larger, extremely dangerous debris must be collected. There is no need to eliminate all, but to reach an acceptable risk level for the functioning space crafts and satellites. As there is a peak density in orbits between 800 km and 1,100 km, it sets the main target. (Kaplan, 2010) This area exists, because several fragmentation events happened here, also space debris lifetime can reach several decades in this area. (Ansdell, 2010)

There are numerous technological innovations, and we are still in the phase of exploring them. Technological requirements involve quick development and installation, minimum mass to launch into the space. Hopefully, the talents will be able to identify the right solution before corrective action becomes much more expensive. A bigger concern might be political, legal and economic aspects. Economic requirements include the inputted effort produces a noticeable improvement in the LEO environment and feasible costs. Political requirements involve transparent development, installation and operations. If it is realized, nations will not be afraid to lose their active satellites. Finally, legal conditions need to be established ensuring compliance with existing international laws. (Ansdell, 2010)

No governments will likely to take actions until catastrophic events will happen frequently, even then solution will come slowly. (Kaplan, 2010) The nature of global space activities implies all nations should be involved in the solution. However, international cooperation rarely result cost-effective solutions in unknown technological areas. The classic problem of free riders will also arise, as three countries (United States, Russia, China) are responsible for the major fragmentation, yet all nations would benefit from the mitigation. (Ansdell, 2010)

According to Marshall Kaplan, an orbital debris expert at Johns Hopkins University, there will be no practical solution to remove the space debris within a decade. We are in lack of technology and cooperation. As Kaplan said, "*the space debris cleanup is a growth industry, but there are no customers. In addition, it is politically untenable*." (David, 2011)

3.1.1 Encounters of space clean-up

Nishida *et al.* (2009, p. 278) mentions three related dimension that active space debris removal is facing: final approach, communication and illumination. The main obstacle lies in the fact that the target (debris object) is uncooperative (*Ibid.* p. 278). This means that strategies are needed in order to handle the motions of the targets and prevent collisions between the target and the hunter. Depending on the communication and illumination conditions, there can be amplifications of the risks in relation to the activity.

The communication or the lack of it during the final approach can be derived from the undeveloped technological solutions. (Nishida *et al.* 2009, p. 278) Continuous contact with the spacecraft during the final approach of eliminating the object would be useful with the human supervision through a chain of ground stations. The distance between the object and the chaser will be small during the capture of the target, which in turn, can obstruct the communication signals from reaching the ground stations. (*Ibid*. p. 278)

To this, challenges occur when considering the illumination conditions in low-Earth orbit while targeting the object. As Nishida *et al* (2009, p. 278) state, the navigation system sensors and chaser's power supply require visible light, but due to the short orbital period (90–100 min), the direction of the Sun changes rapidly in time as well as the factor that a large part of the orbit is eclipsed. These are the challenges which influence the navigation systems and chasers, and need to be aware of and considered as potential risk factors.

3.2 Emerging opportunities

As previously discussed, there are numerous challenges addressing space debris removal. However there are some opportunities that arise in conjunction with the activity, which will be discussed in this chapter.

The primary and most evident opportunity that appears is the scope of international cooperation. Johnson (2007, p. 14) highlights that an international approach is highly likely required in order to remediate the ecosystem of the near-Earth space. This cooperation brings forth opportunities to develop strong international collaboration ties. In addition to that, the shared responsibility gives the basis for the collective security globally.

Another possible opportunity arises for some companies that can be driven by the benefits of receiving financial funding from the government and take part in extensive projects connected to the debris removal activity. The issue gives an opportunity for innovation development, as companies can propose and design specific tools which are attached on little satellites and launch them in space in order to enlarge the pull effect and accelerate the re-entry of debris into the atmosphere of the planet. Companies have the possibilities to challenge themselves on creating smart solutions to contribute resolving the issue.

3.3 Determination of space debris removal with the business model

The current chapter will focus on the evaluation of the effectiveness of space debris removal in terms of a business model with chosen indicators.

Taking into consideration the theoretical framework and the business model presented in the first chapter (see also Figure 1), an attempt to give an evaluation to the space debris removal and its effectiveness in business terms is performed. Johnson (2007, p. 9) has brought out the principle concepts of space debris removal, which incorporates two aspects: the technical feasibility in the near-term and the economic viability (affordable and with the acceptable cost-benefit ratio). This principle corresponds to the business model accompanied by technical inputs and economical outputs. As discussed beforehand, the technical aspects regarding the space debris removal is in the developing phase. Therefore, it is complicated to give a valid estimation to the feasibility and the output of the technological innovation performance and to the effectiveness of these techniques. However, certainly from the economical viewpoint, the very specific technological solutions to use in the elimination process require great financial resources, therefore the price is considerably high. The received profit is not substantial and thus the cost-benefit ratio in monetary terms will put the viability of the business of space debris removal under the question.

The value created from the debris removal is mostly related to the social factors, as the authors believe the output serves for the global purpose. Space debris removal implementation prevents the catastrophe of the collapse of space systems which are essential for the economic well-being and security reasons. In addition to that, the safety of spaceships, -stations and astronauts is a major issue and requires the elimination of the dangerous objects from the low-Earth orbit. Taking into account the market, we can state once more that the social component is involved. There is no definite market to address directly in this business field, therefore the only considerable target group who benefit from the removal activity is the nation globally. Regarding the competition, authors believe there are only a few players in this area, as abovementioned countries U.S, China and Russia, who can take the leading position in this field. They can establish a value network and create a competitive environment, provided by the resources they possess.

Based on the outcomes of the analysis, the authors do not see space debris removal as an effective business model at this present moment. There are positive outcomes of this activity and it is an actual issue that needs to be addressed and tackled, but evaluating the technological inputs and economical outputs with the business model elements, it appears that the profitability and the effectiveness are not very high. The technology required is very unique and expensive and the return from the investments would not be profitable. However, as the technology and innovation is developing rapidly, the authors do not exclude the possibilities of cheaper technological solutions, wide international cooperation, the shared responsibilities and therefore the increase of the effectiveness of space debris removal in the future.

3.4 Recommendations

This chapter will bring forth some recommendations in order to confront the challenges related to the space debris removal issue. Any removal program needs to have two phases: one aiming to collect large objects, and another for small debris elimination. It is important to identify the two modes, as they require different technologies and equipment. In the short term, we need to focus on larger debris in the peak densities areas (orbits between 800 km and 1,100 km), but in the long term permanent orbit maintenance program requires systems to patrol from low to geostationary altitudes.

For the economic aspect, nations need to cooperate, international advisory committees have to evolve regulatory organizations to legislate and execute debris proliferation issues. Programs and technologies may be financed by taxation, multi-governmental programs or entrepreneurial innovation. (Kaplan, 2010)

Conclusion

This research paper aimed to understand and assess the extent of the space debris removal activity in terms of the business model. The implemented approach to investigate the topic was exploratory in conjunction with qualitative method reviewing external secondary data. The results of the research determined that the principle concepts of space debris removal correspond to the business model framework including technical inputs and economical outputs. There are different indicators available to measure the effectiveness, and these vary according to the business and the key activities. Several methods exist to implement space debris removal; however, there are predominantly more challenges than opportunities accompanying these activities. The research revealed that currently space debris removal is not effective in terms of business model. The indicators employed in order to understand the effectiveness showed the outcome of little effectiveness of space debris removal activity in the business model. However, as this field of expertise is not thoroughly investigated, the authors believe the increase of the effectiveness of space debris removal in the future can occur through the innovation development, technological processes and the shared responsibility. This allows elaborating on the direction and the ideas for the further research concepts, as with the fast-paced changing environment and the debris removal methods under experimentation will allow to collect further information and data to carry perhaps more technical oriented researches with validated results.

References

Ansdell, M. (2010): *Active space debris removal: Needs, implications, and recommendations for today’s geopolitical environment.* Journal of Public and International Affairs, available at <https://www.princeton.edu/jpia/past-issues-1/2010/Space-Debris-Removal.pdf.> (consulted 4/12/2015)

Byrd, D. (2013): *Space junk headed for a cascade of collisions.* Earthsky.org webpage, available at <http://earthsky.org/space/time-to-do-something-about-space-debris-experts-say> (consulted 4/12/2015)

Chesbrough, H., & Rosenbloom, R. S. (2002). The role of the business model in capturing value from innovation: evidence from Xerox Corporation's technology spin-off companies. *Industrial and corporate change*, *11*(3), 529-555.

David, L. (2011): *Ugly Truth of Space Junk: Orbital Debris Problem to Triple by 2030*. Space.com webpage, available at <http://www.space.com/11607-space-junk-rising-orbital-debris-levels-2030.html#sthash.9Zfk4k3E.dpuf> (consulted 8/12/2015)

Garcia, M. (2013, September 27). Space Debris and Human Spacecraft, available at <http://www.nasa.gov/mission_pages/station/news/orbital_debris.html> (consulted 7/12/2015)

Hedman, J., & Kalling, T. (2003). The business model concept: theoretical underpinnings and empirical illustrations. *European Journal of Information Systems*, *12*(1), 49-59.

Johnson, N. L. (2007). Debris Removal: An Opportunity for Cooperative Research?.

Hildreth, S. A. (2014): *Threats to U.S. National Security Interests in Space: Orbital Debris Mitigation and Removal.* Congressional Research Service, available at <https://www.fas.org/sgp/crs/natsec/R43353.pdf> (consulted 8/12/2015)

Kaplan, M.H. (2010): *Space Debris Realities and Removal.* University presentation, available at <https://info.aiaa.org/tac/SMG/SOSTC/Workshop%20Documents/2010/Space%20Debris%20Removal%20-%20Kaplan.pdf> (consulted 12/12/2015)

McCormick, P. K. (2013). Space debris: Conjunction opportunities and opportunities for international cooperation. *Science and Public Policy*, *40*(6), 801-813.

Müller-Christ, G. (2011). *Sustainable management: coping with the dilemmas of resource-oriented management*. Springer Science & Business Media.

NASA (2013): *Space Debris and Human Spacecraft.* Nasa webpage, available at <http://www.nasa.gov/mission_pages/station/news/orbital_debris.html> (consulted 12/12/2015)

Neely, A. (2002). *Business performance measurement: theory and practice*. Cambridge University Press.

Nishida, S. I., Kawamoto, S., Okawa, Y., Terui, F., & Kitamura, S. (2009). Space debris removal system using a small satellite. *Acta Astronautica*,*65*(1), 95-102.

Redd, N. T. (2013): *Space Junk: Tracking & Removing Orbital Debris.* Space.com webpage, available at <http://www.space.com/16518-space-junk.html#sthash.MhX1CgNr.dpuf> (consulted 20/12/2015)

Tirole, J. (1988). *The theory of industrial organization*. MIT press.

Venkatraman, N., & Ramanujam, V. (1986). Measurement of business performance in strategy research: A comparison of approaches. *Academy of management review*, *11*(4), 801-814.