Influence of Sustainable Development of Space Activities on Earth Ecology

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Abstract. In the age of New Space, faces the global problem of orbit space constraint. Sustainable development of space activities will be possible only when space users implement technologies and practices suitable to avoid accumulating objects in orbit. Artificial debris in orbital space has reached catastrophic proportions. This harm the Earth's ecology leading to increased steps to transform a planet that is unsuitable for life. Based on the fractal analysis, the graphic interpretation of the components of SWOT-analysis of development of the rocket and space industry is built. It is found that the weak side and threat to the activities of the aerospace industry is the insufficient funding of implemented projects and inefficient distribution of finances between its components: science and production. It is proposed to use blockchain technology as an effective tool for the cybersecurity of space objects. The ecological risks from space activities that affect the Earth's ecology are analyzed. It is proven that the prevention of severe environmental consequences and minimization of the negative impact of the above threats require the introduction of environmental management systems in space activities.

1. Introduction

In order to increase the interest of stakeholders in space exploration and ensure the effectiveness of sustainable space activities programs, it is necessary to build the capacity of many countries in the sector of essential space technologies, ensure a responsible attitude to space of new space agents, raise public awareness and activism.

The increase in the number of countries and private operators operating space systems in geostationary orbit significantly highlights the long-term sustainability of space activities due to the increase in the population of orbital debris, especially in low Earth orbits, congestion of individual families of orbits, and various radio interference problems.

At all hierarchical levels of the economy (national and international), there is a corresponding list of standards and guidelines in the field of waste prevention and protection of spacecraft. Projects to prevent the formation or disposal of garbage require certain costs. To ensure the competitiveness of space activities, all agents (space users) must participate in these projects. Measures to prevent the formation of space debris will be effective only if it is an integral and permanent element of activity in orbit.

The problem of garbage generation and the protection of spacecraft is a component of international security. In determining the feasibility study of rocket and space technology projects, it is necessary to carry out a safety assessment, to determine the probability of collision of the payload with other active
payloads and the general environment of space debris. The probability of a collision depends on the following main factors: orbit configuration, duration of stay in orbit, physical dimensions, and spatial density of objects at a given height. Coordination of working procedures for the necessary disposal or transition to a higher orbit or diversion to a lower orbit should be considered before starting the normal mode of operation of space systems.

It is necessary to determine the compliance of space waste disposal with existing standards/guidelines of international organizations in the field of sustainable space activities [1]: the maximum service life of the equipment in orbit at an altitude of up to 2000 km should not exceed 25 years, after which it must be disposed of; compliance of the technological capabilities of the platform – the extent to which on-board systems allow autonomous maneuvers to divert from orbit/transition to another orbit without interference from the Earth; criteria for determining the service life of rocket and space equipment; achieving a 90 percent probability of successful diversion of used satellites and analysis of the operation of large satellite groups, etc.

When building a model for calculating the expected costs of creating new rocket and space equipment, taking into account, the uncertainties indicate the main elements of the information base [2]. One can agree with the opinion of the authors that the creation of new rocket and space equipment is an innovative project with an appropriate list of risks in each phase of the product life cycle. Nevertheless, the weaknesses of the authors' study are as follows: risks of only two stages of the life cycle of space equipment are considered: R&D and production. Limitation to the first two phases of the life cycle does not allow to carry out corrective actions to mitigate risks, take correction factors and changes in temporality, etc.

The focus on risk identification in building a methodical approach to solving the quantitative risk assessment of projects to create rocket and space equipment took place in further studies of the authors [3]. The advantage of the study is taking into account risk factors when calculating the overall effectiveness of projects. Nevertheless, there appears a debatable question: the calculation of the overall effectiveness of the project can be determined only by taking into account the integrated risk indicator of the project, which is determined by all phases of the life cycle, not only the first and second ones.

When substantiating the method of risk assessment in the creation of rocket and space equipment [4], the aggregation of local risks in 8 stages is carried out: concept; technical project development (pilot and sketch project); working design documentation development; development of technological documentation and technical processes; model and prototype creation; ground tests; flight tests and revision of documentation; production launch. Unfortunately, the article focused only stage 5 of "model and prototype creation," which is insufficient to substantiate the proposed method.

In the study [5], the life cycle risk mitigation methods of complex science-intensive projects in the field of rocket and space equipment are considered. For example, risks specific to each stage of the rocket and space equipment project (research and development; designing preproduction; process design; assimilation of new rocket and space equipment; production of rocket and space equipment; transportation; operation of rocket and space equipment and sales of space services, disposal of rocket and space equipment) and possible losses are listed. For example, for the stage of "disposal of rocket and space equipment," the authors identify two types of risk: accidents during the dismantling of a structure (loss — the cost of work to eliminate the consequences of an accident) and environmental pollution due to violation of the rules of disposal of products (the cost of work to eliminate the effects of environmental pollution).

Of course, this is an incomplete list of environmental risks that arise during space activities. For example, there are subclasses of environmental risks in the upper atmosphere and near-space: risks of mechanical contamination of territories and damage to people by debris of spent spacecraft; risks of chemical contamination of territories with remnants of space equipment; threats of spacecraft collisions in near space; risks of pollution of near-Earth space – space the debris; thermal risks that threaten the physical condition of spacecraft and the lives of astronauts; risks of radiation damage to equipment and people; exo-threats associated with the physical properties of the outer shell of the earth atmosphere.
To make it impossible for fragments to hit people, specialists carefully calculate the trajectory of deorbiting used satellites to ensure that the probability of fragments of space equipment unburnt in the atmosphere hitting people was less than 0.01% [6]. At the same time, the amount of space debris currently in planet’s orbit reaches about 500 thousand objects [7].

It should be noted that the European Space Agency (ESA) and the US National Aeronautics and Space Administration (NASA) use the concept of Life Cycle Assessment (LCA) when evaluating space products. The document "Agency Risk Management Procedural Requirements" dated 16.12.2008 describes the procedure for analyzing the life cycle of space equipment in its broadest sense.

The procedural risk management system is described by four domains (SMCS): Safety, Mission Success (Technical), Cost, and Schedule [8]. At the same time, the Performance Measure is actively used as a general indicator of assessing the degree of compliance with the implementation of project objectives following the main domains (SMCS) of the process. The following measures are possible to ensure the productivity of the project: safety effectiveness – avoiding injury, death, or destruction of crucial assets of space activities entities; mission success rate (technical) – the number of observations obtained and other technical parameters; cost efficiency – project implementation within the allocated budget; efficiency of the implementation schedule – compliance with the stages of project implementation and its plan.

The main disadvantages of the Agency Risk Management Procedural Requirements are the inability to determine the impact of space activities on the environment and to consider the liquidation value when calculating the value of space activities as its component – the cost of space waste disposal. Determining the environmental impact of space objects is considered in the development of requirements and management process of NASA programs and projects [9]. It is provided for the formation of a plan of measures to be taken to protect the population, astronauts, equipment, and property of NASA, as well as identification of all activities, such as safety, reliability and maintainability, quality assurance, safety guarantees of software, environment, related to design and testing, including preventing the formation of orbital debris [9]. An environmental assessment is a mandatory element of the cost of space products.

National regulatory requirements are better taken into account when licensing space activities. For example, following the [10], the issues of forming a plan to prevent the risks posed by inactive space objects to both the Earth's environment and near-Earth space are considered, and assessments of compliance with moral, financial, professional, and technical requirements are carried out within the permitting procedures.

However, there is almost no mention of the harmful effects of such technologies on natural ecosystems, severe disturbance of the ecological balance of territories, natural processes, chemical pollution of the air and the environment. It is not profitable for computer corporations and digital equipment manufacturers to increase the cost of their products by increasing their environmental safety; they are limited to compliance with superficial environmental standards established by the countries’ laws in which markets they operate. Extensive research and production centers, which create artificial satellites of the Earth, rockets, spacecraft, and all other objects of the space industry, directly or indirectly involved in this process, are no exception. Therefore, it is necessary to further study the upper atmospheric environmental risks of space activities in the age of New Space.

All this significantly actualizes the problem of studying the impact of human space activities on the Earth's ecology to ensure sustainable development by preventing and eliminating environmental risks.

2. Method

The urgency of the direction of research involves the identification of new tendencies, trends, strategic research areas, technological advances that, in the long run, can significantly affect the economic and social development of space activities in the future. For this purpose, in implementing the procedure of forming alternative scenarios in solving forecasting problems, there is a need to involve expert assessment methods, among which SWOT analysis, Delphi methods, and morphological analysis are mainly highlighted. Cognitive modeling is involved for in building scenarios concerning the selected
alternatives, which gives a chance, based on the proposed mathematical methods, with practical certainty to receive a substantiated scenario for decision-making.

The computation algorithm is designed to perform a SWOT-analysis of the object, analysis of its strengths (Strengths), weaknesses (Weaknesses), opportunities (Opportunities), and threats (Threats). The computation algorithm supports all the procedures, models, and methods necessary for SWOT analysis.

3. Results and discussion

In the phases of the life cycle of rocket and space equipment, it is necessary to take into account all phases following European standards: phase 0 ‘Mission analysis/needs definition’; phase A ‘Feasibility’; phase B ‘Preliminary design’; phase C ‘Detailed design’; phase D ‘Qualification & Production’; phase E ‘Operation’; phase F ‘Utilization.’ The Ukrainian government plans to become a member of the European Space Agency, which draws increased attention to taking these phases of the life cycle of rocket and space equipment. For example, in the phase of ‘Mission analysis/needs definition,’ it is necessary to research market needs in the design and production of innovative rocket and space equipment.

The specifics of the proposed model are that the data subject to analysis have both qualitative and quantitative characteristics. The advantage of the model is the compactness of development due to the use of one platform and the efficiency of use due to the absence of the need to reload data into a specialized system. For the fractal analyzing, the graphic interpretation of comparison of components of SWOT-analysis of development of the rocket and space industry is built:

- **S1** – supplier's responsibility for national security;
- **S2** – unlimited access to unique resources;
- **S3** – high level of qualification of the industry staff;
- **S4** – advanced and unique technology;
- **S5** – diversification of financing sources (state, foreign capital);
- **S6** – brand awareness on the world market;
- **S7** – formation of aerospace clusters;
- **S8** – dominance of state security goals;
- **W1** – low profitability;
- **W2** – high cost of production;
- **W3** – limited policy to promote products on the market;
- **W4** – low funding for personnel development programs of industry enterprises;
- **W5** – reduction of public funding;
- **W6** – lack of working capital;
- **W7** – low level of cybersecurity;
- **W8** – obsolete fixed capital;
- **W9** – narrow product range;
- **W10** – reduction of public funding;
- **O1** – improvement of business structures;
- **O2** – independence from the exchange rate;
- **O3** – capacious world market;
- **O4** – availability of resources;
- **O5** – oligopolistic nature of competition;
- **O6** – conversion of competing firms;
- **O7** – state support for critical infrastructure;
- **O8** – introduction of Agile-management principles at high-tech enterprises;
- **T1** – emergence of the latest legislative restrictions;
- **T2** – emergence of foreign competitors;
- **T3** – priority of public supplies;
- **T4** – priority nature of the development of the aerospace industry;
- **T5** – changing consumer preferences;
- **T6** – priority of state interests;
- **T7** – influence of political factors (Figure 1).

According to the results of SWOT analysis, it is found that the weak side and threat to the activities of the aerospace industry is the insufficient funding of implemented projects and inefficient distribution of finances between its components: science and production. It should be noted that the aerospace industry is a critical infrastructure – the development of the aerospace industry is a component of national security. It is necessary to improve the security components of industrial enterprises and scientific institutions in, of space activities: economic, energy, personnel, and cybernetic security [11].

However, there is almost no mention of the harmful effects of such technologies on natural ecosystems, severe disturbance of the ecological balance of territories, natural processes, chemical pollution of the air and the environment. It is not profitable for computer corporations and digital equipment manufacturers to increase the cost of their products by increasing their environmental safety; they are limited to compliance with superficial environmental standards established by the countries’ laws in which markets they operate.
Blockchain systems in the space sector help create conditions for storing, processing, and analyzing a huge amount of information. This information should be included in the agreement and is the only one that is important for space market participants, representatives of the economy’s financial sector. Blockchain technology as a high-tech control system will allow combining communications into a single whole, provided the programmable artificial intelligence is adjusted to the needs of each user [12].

The network can track the trajectory of space objects on the Internet, using techniques and tools for monitoring: collection, processing of information in the system “production process-consumption”. Prospects for the use of blockchain technology in this sector have significant potential: this technology is gradually expanding in related industries – a global network of resource management is being formed at various hierarchical levels, particularly at industrial enterprises.

The introduction of principles, methods, tools and technologies of Agile management allows companies to make an innovative "explosion" in management functions: planning, organization, marketing, motivation, control, accounting, audit, etc. According to a study by Boston Consulting Group (BCG) [13] the main benefits of implementing Agile Management have cost reduction by 25-35 %, product and service quality improvement by 20 %, acceleration of new products and services by 100-200 %.

The priority task of Agile management is the possibility of overcoming barriers to the introduction of innovative solutions, first of all, information one. The information vacuum deprives experts of the opportunity to make a relevant assessment of the decision. Therefore,—information and methodical support of the management system at the enterprise is required, which is provided by a system of information support, namely – communication support. Although it is possible to take appropriate measures to reduce the information asymmetry (creation of a single information base, provision of additional information, coordination of interests of economic agents, use of screening techniques, etc.), it is impossible to avoid the minimum value [14][15][16]. Information users have a particular interest. If the interests reach a difference, the information asymmetry reaches a maximum value. As a result, public benefits and effects are reduced.

Overloading the Earth's orbit with space debris is one of the most serious problems of today. The worst-case scenario shortly is described by the so-called Kessler effect, according to which the excessive accumulation of space debris in Earth orbit will lead to the complete unfitness of near space for human
use and colonization, primarily due to the "domino principle" according to which colliding of spacecraft with objects of space debris inevitably disables them, as a result of which the amount of space debris only increases.

Problems related to the collision of spacecraft with each other and with elements of space debris are also extremely relevant. Over the entire era of astronautics, more than 6,000 different satellites – research, biological, spy, telecommunication, and meteorological ones – have been launched into near space. Furthermore, about 800 of them are currently working condition in orbit. Colliding, many of them turn into space debris, which results in relatively large economic and environmental losses.

Chemical decomposition products from used space objects in orbit, i.e., solid and liquid rocket fuel components, also pose a significant threat. First of all, this is about the toxic substance hydrazine, which is part of rocket fuel. For example, nitrogen trifluoride, is a greenhouse gas and negatively impacts the environment because it provokes global warming. Perchlorates have a detrimental effect on the vegetation of the Earth.

A particular type of thermal risk is Joule heat, which appears due to the action of electric currents of the magnetosphere. It entails significant warming of the upper atmosphere in the polar regions, and usually, this phenomenon manifests itself in magnetic storms. Its peculiarity is that such warming occurs unevenly, and therefore, there are significant risks of spacecraft with crews getting into such areas in the thermosphere.

There is a whole range of threats of possible environmental pollution: mechanical, chemical, thermal, biological; and on the other hand – threats to both astronauts dealing with high-precision equipment and the population of some territories – areas of possible damage directly to the Earth's surface. Preventing severe environmental consequences and minimizing the negative impact of the above threats require environmental management systems. One of the possible ways to increase the economic security of space activities and compensate for potential damage from adverse effects for the environment is the use of organizational and economical methods of environmental risk management of space projects and production activities of the rocket and space industry [17]. In the context of the expansion of the practice of commercial creation and operation of space systems, the entry of national enterprises of the rocket and space industry on the international market, the development of commercial space activities, the issues of improvement of economic protection and environmental risk management in the implementation of space programs take on increasing importance [18].

Insurance is the most common way of financial protection and risk management. Insurance provides compensation for damage without affecting its size or the likelihood of its occurrence [19]. Environmental insurance is a method of environmental risk management related to the implementation of space programs in space activities. Recently, companies participating in space activities have begun to show increasing interest in insuring environmental risks in implementing space projects.

Experts also suggest the following [20]: Specify the responsibility for environmental pollution for industries, in this case — rocket and space industry, with a clear list of measures to eliminate the effects of adverse effects of rocket and space equipment for the environment, both in the normal course of the operation and in accidents. However, this rests on the lack of specialists in the field of space ecology. Therefore, one of the ways and first steps to solving environmental pollution is creating a corresponding separate specialty at the environmental faculties of universities — "space ecology". These specialists will be involved in the development of space projects taking into account all the nuances of the impact of rocket and space technology on the environment, which will help prevent possible negative impacts.

The slow exchange of information delays the achievement of harmonious development goals – the transformation of human space activities into sustainable development and the combination of interests of all market participants. Sustainable development of space activities will be possible only when space users implement technologies and practices suitable to avoid accumulating objects in orbit.
4. Conclusion
The formation of the methodological platform of Agile management takes place at the stage of social production of Industry 4.0. According to the attributive approach, innovative system change is possible only at cardinal changes of its functional properties (attributes).

Overcoming information asymmetry is a crucial task, as it hinders the harmonious development of the necessary technologies, preventing market participants from adequately assessing the risks and opportunities associated with building an innovation system in the New Space era.

Prospects for research in this scientific field are related to the limitations of research. For example, in the field of economic assessment of environmental risks related to the space activity of humanity, it is necessary to improve the methodology for determining environmental damage to determine the actual amount of insurance. With that, it is necessary to make a list of correction factors that will consider the following parameters: service life, disposal value, the ratio of the cost of orbital injection and recovery, the cost of deferred decisions.

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