DOI: 10.13009/EUCASS2019-1064

8th european conference for aeronautics and space sciences (eucass)

Towards an Ontology of Sustainable Space Logistics

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Abstract

Logistics is defined as "the management of the flow of things between the point of origin and the point of consumption in order to meet the requirements of customers or corporations" [1]. While Space logistics is a new field of its own and, although many concepts can be inherited from current logistics practices, it requires the creation of a new set of technologies and competencies. Moreover, space is a unique and fragile resource that is why it is key to develop this ecosystem with a long-term and sustainable vision.
This paper introduces the foundation for an ontology of Sustainable Space Logistics, by characterizing the logistics nodes, the resources to manage, and the space logistics activities.

1 Introduction

In recent years, the space sector has undergone massive changes. At first the space meant exploration of the Solar System (manned and unmanned missions), observation of the Earth and the Universe, and include telecommunication as a commercial application. Other important services developed later on with the GPS navigation system and its competitors. With the development of NewSpace: the revolution that democratised the access to space through cheaper launches, cutting-edge technologies and miniaturisation, new opportunities are now possible. As an example, space exploration is capturing more attention. The world players plan to explore the Moon, Mars and beyond with manned and unmanned missions, relying on the utilization of space resources (e.g. space mining). Morgan Stanley forecasts the space industry will be worth more than US$1.1 trillion by 2040, up from U.S.$350 billion, currently. These conditions enable to rethink the way we explore, use and do business in space. But sustainable space activities are impossible without an efficient supply-chain. How can Space Logistics activities be described and represented in order to build the foundation for Space Logistics services and systems?
Logistics is defined as "the management of the flow of things between the point of origin and the point of consumption in order to meet the requirements of customers or corporations" [1], while according to the AIAA Space Logistics Technical Committee, space logistics is "the theory and practice of driving space system design for operability, and of managing the flow of material, services, and information needed throughout a space system lifecycle". This definition in its larger sense includes terrestrial logistics in support of space travel, including any additional "design and development, acquisition, storage, movement, distribution, maintenance, evacuation, and disposition of space materiel", movement of people in space (both routine and for medical and other emergencies), and contracting and supplying any required support services for maintaining space travel.
Numerous innovations in the space segment are still needed to revolutionize space operations, such as space engineering, namely, how to manufacture, transport, store, deliver and remove materials, goods, structures, and humans in space. As such, space logistics is a new field of its own and, although many concepts can be inherited from current logistics practice, it requires the creation of a new set of technologies and competencies. Moreover, as space is a unique and fragile resource, e.g. our space infrastructure can be severely impacted by debris collisions or strong space weather storms. That is why it is key to develop this new ecosystem with a long-term and sustainable vision.
This paper introduces the foundation for an ontology of Sustainable Space Logistics, by characterizing the logistics nodes, the resources to manage, and the space logistics activities.
The Background section gives an overview of the common concepts and definitions of Space Logistics. The Methodology section explains how the study was conducted. The section 4 described the proposed ontology of Sustainable Space Logistics, while the Discussion section discusses the impacts and the limits of this work.

2 Background

The MIT Strategic Engineering laboratory [3] is the main contributor to the domain of space logistics. It focuses on supply chain management and logistics architecture. The problem is decomposed into four steps:

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- model supply chains and supplies characteristics based on Earth analogues
- develop nodal networks to represent space logistics
- study demand and supply along the network while taking uncertainties into account
- perform trade space exploration and optimization for particular applications, including space tugs, mars exploration and constellations reconfiguration

This project resulted in a common modelling framework and a software solution called SpaceNet [4] which is a MATLAB/excel based tool used to model and optimize diverse logistics architectures. Other publications include lessons learned from previous missions, study of remote manufacturing, spare parts management and on-orbit assembly.

The Kennedy Space Center has developed a tool called E2O Sim that focuses on simulating Earth to Orbit supply chains [5]. The simulation considers information and material flows. It is based on discrete events and relies on standard Supply Change Management models. The input is a representation of the supply chain with a simple framework (plan, source, make, deliver, return functions, etc.). This simulation has been used in the context of human flight and space exploration.

The Johnson Space Center has developed a framework to estimate consumption, supply needs and threats related to logistics for crewed missions [6].

The University of Illinois has developed an analytical model for staged space logistics planning [7]. The strategy consists in using previously deployed stages to support further deployment. The model returns the initial mass in LEO and optimal staging strategy.

Multiple actors are actively pursuing solutions for in orbit servicing. SpaceLogistics LLC is a wholly owned subsidiary of Northrop Grumman that offers cooperative in-orbit satellite [8]. Other initiatives include:

- Orbital Express Space Operations Mission
- Deutsche Orbitale Servicing (DEOS) Mission
- NASA Robotic Refueling Mission (RRM)
- Phoenix Program by DARPA
- Raven—The Autonomous Rendezvous Experiment
- CleanSpace One
- ConeXpress Orbital Life Extension Vehicle
- Vivisat Mission Extension Vehicle
- McDonald Dettwiler Associates's Space Infrastructure Servicing (SIS) Vehicle
- Electro Dynamic Debris Eliminator (EDDE).

3 Methodology

The objective is to find the concepts and relationships that enable to describe the space activities, and to represent in a synthetic way the ecosystem in order to find the optimized solutions to space logistics needs. This work proposes to adopt a problem-solution approach. Existing logistics ontologies were identified through the literature review. The classes and their hierarchy were defined, and the instances created using an extensive literature review in space activities.

This study is mainly based on the review of literature, as well as and qualitative research analysis to identify the elements of the ontology.

The software Protégé [9] was used to create the ontology and store the instances.

4 Proposed Ontology of Sustainable Space Logistics

4.1 Resources

This class lists the resources that need to be transported to the point of consumption:

- Telecommunication and observation satellite
- Scientific equipment
- Means of transport
- Crew
- Habitation and infrastructure
- Storage and restraint
- Propellant and fuels
- Waste and disposal
- Raw material
- Information

The classes of supply identified by the Space Logistics MIT project was extended with information. The resources managed can include abstract items such as information.

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4.2 Nodes

Two types of nodes exist:

- Point of origin
- Point of consumption

The nodes can be of two types:

- Orbital Nodes.
- Surface Nodes.

4.3 Space Activities

In order to forecast the flows of resources, the activities at the nodes were identified to justify the flows of resources:

- Telecommunication and observation
- Positioning and navigation
- Exploration and Research
- Repairing
- Fuelling
- Manufacturing and assembly
- Mining
- Infrastructure building and leasing
- Human presence
- Surveillance
- Cleaning and recycling

4.4 Logistics activities

The logistics activities are derived from the logistics domain:

- Transportation
    - Launch and landing
    - Dispatching
- Warehousing and storage
- Packaging and unitization
- Inventory
- Information and control

5 Discussion

This ontology aims to help the space community to better capture, understand, communicate, design and analyse space activities involving logistics:

- **Understand**: the ontology could be used to represent the logic of logistics logic. It gives a simple representation of the elements and their relationships involved in the supply chain. This ontology will be used to visualize the elements of interest to design futures space logistics services.
- **Analyse**: The next step will be to use quantitative models to characterize the future potential logistics needs and to measure and compare the optimized space logistics solutions regarding usage scenarios.
- **Innovate**: this ontology will also be used to scout technologies for the space logistics services, and foster the technology transfer to space applications.

However, this work is a first attempt to define a common and shared vocabulary around the space logistics activities and has not been validated and adopted by the main space actors yet. The next step will consist in validating the ontology and identifying the community around the elements of the ontology.

6 Conclusion

This study introduced an ontology of sustainable space logistics based. The next steps will consist in using the proposed ontology to understand and analyse the space logistics needs. The authors invite the community to take part in this initiative, challenge this work. In order to build the community around Sustainable Space Logistics, a Zotero library was created to store and share the bibliography on the topic [10].

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7 References

[1] 'Space Logistics'. In Wikipedia, the Free Encyclopedia, 7 March 2019. https://en.wikipedia.org/w/index.php?title=Space_logistics&oldid=708762939.
[2] 'AIAA Space Logistics Definitions'. Accessed 11 August 2019. https://info.aiaa.org/tac/SMG/SLTC/Web%20Pages/Definitions.aspx.
[3] 'MIT Strategic Engineering Research Group'. Accessed 2 June 2019. http://strategic.mit.edu/logistics.php.
[4] 'SpaceNet'. Accessed 2 June 2019. http://spacenet.mit.edu/.
[5] Fayez, M., D. Cope, A. Kaylani, M. Callinan, E. Zapata, and M. Mollaghasemi. 'Earth to Orbit Logistics and Supply Chain Modeling and Simulation for NASA Exploration Systems'. In Proceedings of the 2006 Winter Simulation Conference, 1462–69, 2006. https://doi.org/10.1109/WSC.2006.322914.
[6] Lopez, P., E. Schultz, B. Mattfeld, C. Stromgren, and K. Goodliff. 'Logistics Needs for Potential Deep Space Mission Scenarios Post Asteroid Redirect Crewed Mission'. In 2015 IEEE Aerospace Conference, 1–10, 2015. https://doi.org/10.1109/AERO.2015.7119161.
[7] Chen, Zhengyu, Hao Chen, and Koki Ho. 'Analytical Model of Space Infrastructure Staged Deployment Strategy in Space Logistics'. In AIAA SPACE and Astronautics Forum and Exposition. AIAA SPACE Forum. American Institute of Aeronautics and Astronautics, 2017. https://doi.org/10.2514/6.2017-5349.
[8] 'Space Logistics Services'. Northrop Grumman. Accessed 2 July 2019. https://www.northropgrumman.com/Capabilities/SpaceLogistics/Pages/default.aspx.
[9] 'Protégé'. Accessed 4 July 2019. https://protege.stanford.edu/.
[10] 'Zotero | Groups > Sustainable Space Logistics'. Accessed 2 July 2019. https://www.zotero.org/groups/2329012/sustainable_space_logistics?