22st DMI: Academic Design Management Conference
Impact The Future By Design
Toronto, Canada, 5-6 August, 2020

A Systematic Thinking Design Research Approach Combining the ConOps with Design Scenario – Use Commercial Cislunar Space Development Project as an Example

Sheng-Hung Lee[*a, b], John Rudnik[b], Chaiwoo Lee[b], Shabnam Fakhr Hosseini[b], Olivier L. de Weck[c], Joseph F. Coughlin[b], and Jonathan Chapman[d]

[a] MIT Integrated Design & Management (IDM); [b] MIT AgeLab; [c] MIT Aeronautics and Astronautics and Engineering Systems; [d] Carnegie Mellon University's School of Design

The design scenario approach has been widely used in the field of design research, design thinking, and creative industries. However, little research has been done to explore the possibility of combining the methodology of ConOps (Concept of Operations) from the field of system engineering with the design scenario approach. Fundamentally, ConOps is an approach to visualize the key touchpoints of the overall process. The design scenario is used as a way to facilitate constructive conversations with participants, and the outcome supports new design research methodology development. This research fuses advanced techniques from design research methodology with a systematic thinking approach in order to better illustrate and capture key moments that constitute the specific task of making a Moon rover and establishing a solar panel system in micro and macro contexts. In particular, the study applied ConOps methodologies to the commercial cislunar space development project and demonstrated the possible learning and reflection by integrating its structure and concepts into design scenario tools. This study is valuable in two aspects: firstly, it can improve the existing design research methodology by fusing the ConOps with the design scenario; secondly, it was a scalable and replicable creative process that experimented with the innovative methodology. Further studies are recommended to focus on combining the systematic thinking approaches, frameworks, and theories with design thinking methodology to tackle systematic innovative challenges to make an invaluable impact.

***Keywords**: Concept of Operations, ConOps, Scenario Design, Design Thinking, Participatory Design*

[*] Corresponding author: **Sheng-Hung Lee** | e-mail: **shdesign@mit.edu**

1. Introduction

The intention of the study was to combine one of the system engineering tools—ConOps with design scenario, a methodology widely used in the field of creativity in order to design and improve the systematic thinking research approach in the commercial cislunar space development project, a three-month system engineering project prepared for 2020 RASC-AL (Revolutionary Aerospace Systems Concepts Academic Linkage) competition under the theme of business innovation managed by The National Institute of Aerospace (NIA) and NASA. It was an experimental methodology-focused study designed to explore and to resolve the following two challenges:

- How to describe and communicate a complex, multidimensional and multifaced systematic challenge effectively with the key stakeholders and internal project team in a professional and intuitive way through ConOps and design scenario?
- How to successfully articulate the intent and present the structure of the project mission through the new experimental methodology?

This project demonstrated the process, reflection and learning of the new experimental systematic thinking research approach merged with ConOps and design scenario, by prototyping and refining through the commercial cislunar space development project. In the context of the study, the term system thinking means to consider thing/project in a holistic way (De Weck, Roos, & Magee, 2016). The goal of the study was to come up with an improved communication systematic thinking tool and framework to capture the essence of core value and message of the project mission comprehensively by leveraging ConOps and design scenario.

2. Literature Review

The study used the commercial cislunar space development project as an example to discuss the definition and the difference between ConOps and design scenario.

2.1 ConOps (Concept of Operations)

ConOps is one of the system engineering tools to communicate the system blueprint with the key stakeholders and internal project teams, serving the purpose of implementation guidance of a complex project in the early stage of a project development process. Shiamzu and Ohkami define ConOps as, 'a framework from the perspective of operational not technology to capture and structure information focusing on what the transformation process will become while a system is developed or under developing' (Shiamzu & Ohkami, 2011).

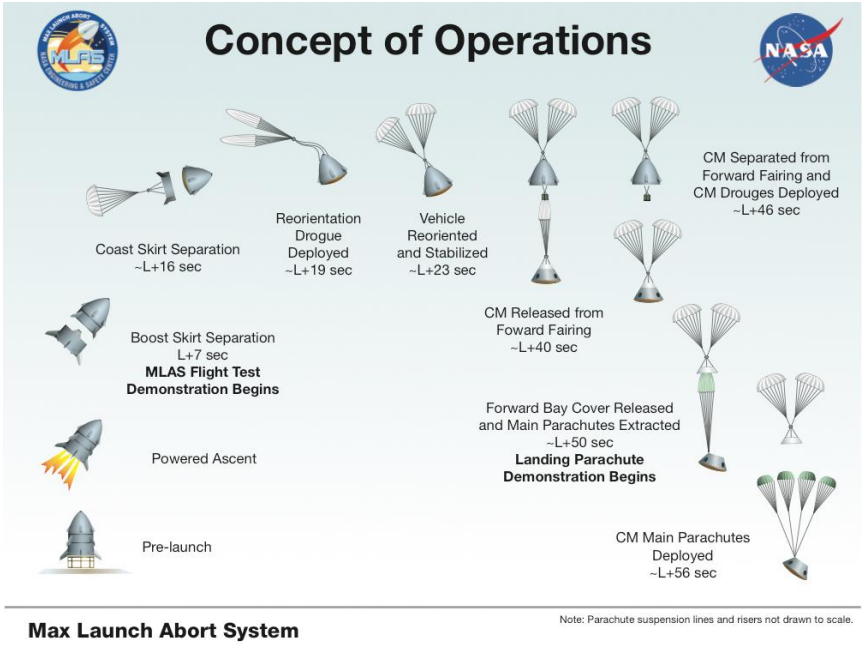
The paper "A Structured Approach for Operational Concept Formulation" by R.J. Lano was the first trackable document to use ConOps in 1980. ConOps has since been applied in many different industries, and the underlying ideas have been interpreted though a wide variety of field-specific meanings and definitions. In the military filed, ConOps is described as 'a verbal or graphic statement that clearly and concisely expresses what the joint force commander intends to accomplish and how it will be done using available resources. Also called CONOPS' (DOD Dictionary of Military and Associated Terms, 2010). The National Aeronautics and Space Administration (NASA) describes ConOps as 'an important driver in the system requirements and therefore should be considered early in the system design processes. The ConOps is an important component in capturing stakeholder expectations and is used in defining requirements and the architecture of a project' (NASA Systems Engineering Handbook, 2007).

ConOps is a tool that is usually applied to solve complex, multidimensional and multivariable systematic challenges. ConOps encapsulates the project mission in a diagram with the estimated time and approximated location of the deployment, the sequence of each phase and the highlighted features of the system to reveal the scope of the mission in a quantitative and qualitative way. 'ConOps document can serve the purpose of containing the information of the project/system required to describe users' needs, expectations, operational conditions, its process, and system features' (Fairley, Thayer, & Bjorke, 1994). According to INCOSE Systems Engineering Handbook (Version 4), '[a] ConOps document can also describe the organization's intent according to an overall

operation or series of business operation' (Walden, Roedler, Forsberg, Hamelin, Shortell, & International Council on Systems Engineering, 2015).

ConOps originates from the military, the government service and aerospace industry, and is commonly used in stakeholder meetings to discuss the initial concepts and ideas of the project. 'A good concept of operations verbally and graphically reflects stakeholders' expectations, so it becomes a platform for validating the system's architecture and technical requirements' (Larson, Kirkpatrick, Sellers, Thomas, & Verma, 2009). While other studies emphasized the importance of having the voice and contribution from users, other than key stakeholders in the process of developing ConOps to ensure the part of focus will keep relevant with users' issues (Fairley et al., 1994). Some studies discussed the potential of tailoring the format and content of ConOps to meet the diverse requirements of each space mission (Owens, 2017).

ConOps is a concept that describes the characteristics of the complex system in the lens of the key stakeholder/evaluator as well as the internal project team to reach the agreement at the principle level before establishing the detailed project requirement process. According to Edward Crawley, Professor of Aeronautics and Astronautics and Engineering Systems at MIT, 'The ConOps is an important component in capturing expectations, forming requirements and developing the architecture of a project or system.' ConOps is an informative approach to convey a project statement of the intent in a graphical and textural way.



[Figure 1] The ConOps of Max Launch Abort System (Source: NASA)

2.2 Design Scenario

Design scenario, scenario, or scenario-based design is a not a new concept and has been widely applied to many different fields of research. Some studies mentioned design scenario needs to reflect the patterns of life, which can echo life-like condition (Swanson, 2016). Other researchers argued that scenarios could provide an explicit guidance and clear vision to inform how a technology can be applied and supported (Nardi, 1992). Still other studies gave its definition as emphasizing on viewing user as an abstracted role and describing the ways how users achieve the goal of the task (Madsen & Nielsen, 2010). Meanwhile Scenario-Based Engineering Process (SEP), a new initiative scenario-related research area, has emerged by bringing engineering process with user-centered requirements to increase the success rate of system development and its application (McGraw & Harbison, 1997).

Design scenario is a context-based design tool to describe the interaction and behavior between the target user/people, selected objects in the context and its environment, which gives the people/audience enough information to understand the why, the who, the where, the when, the what and the how in the context. 'Design scenarios are useful tools for communicating ideas about user actions' (Interaction Design Foundation, 2020). At the same time, design scenario is a tool not only focusing on tasks in details, but also offering a bird's-eye view to gain a holistic perspectives of a project (Nardi, 1992).

Design scenario is presented in the format of one image, similar to the concept of the storyboard with a series of images, by implementing the curated descriptions, relevant sketches, illustrations or photos to bring the scenario to life. Design scenario generation is a mix of ethnography (to understand people's behavior) and relevant technology in the scenario (Nardi, 1992). Applying the design scenario helps people make the right decisions and people can view the essential problems to inform and generate a better human-centered solution. 'Scenario is a tool to support the decision making process and the development of strategies, generating possible futures. In other words, scenarios create different possible futures and not forecast the future' (Ferronato & Ruecker, 2017). Design scenario is a powerful and useful tool in terms of exploration, prototyping, and communication of the design and development stage (Fulton Suri & Marsh, 2000).

[Figure 2] The Design Scenario Showing What Mission to Mars Might Look like. (Source: E71LENA/ISTOCKPHOTO)

3. Case Study – Commercial Cislunar Space Development Project

3.1 Project Overview

The case study, the commercial cislunar space development project, was part of the three-month system engineering project designed for 2020 RASC-AL (Revolutionary Aerospace Systems Concepts Academic Linkage) competition under the theme of business innovation managed by The National Institute of Aerospace (NIA) and The National Aeronautics and Space Administration (NASA). According to the definition from RASC-AL, cislunar space consists of the spherical volume of space with its radius defined by the distance between the Earth and Moon. It represents a prime environment for future business opportunities to improve life on Earth through the use of space. The project was designed to explore the potential business model and strategy that was to expand the economic sphere beyond the Earth's surface, apart from other business opportunities such as tourism, minerals extraction, internment/burial, and in-situ propellant production as potential markets in the cislunar space.

The study applied the selected design thinking approaches and system engineering methodologies to generate the concepts of a lunar energy grid that would empower NASA's future missions in space, based on a call for proposals from the 2020 RASC-AL competition prompts. The project accomplished the allocation and derivation of an energy system and its subsystems, a defined system ConOps, an identity stakeholder map, a designed OPM

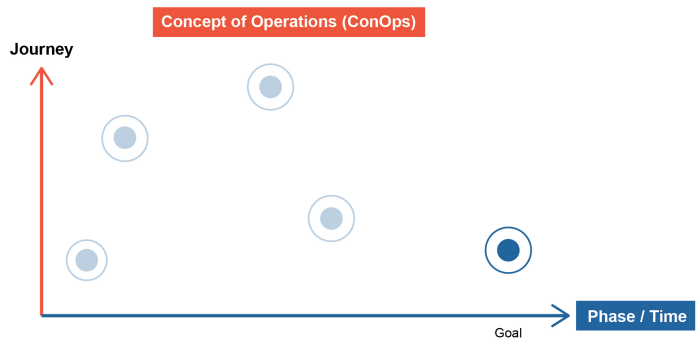
(Object-Process Methodology), and preliminary design architectures. However, this study focused on demonstrating the innovative process to combine ConOps with design scenario.

3.2 Design Process

The intention to apply ConOps, one of the system engineering tools, was to make a blueprint out of the concept for the purpose of communication with the internal team and the key stakeholders in the early stage of project development.

Step1 - Clarify the Mission

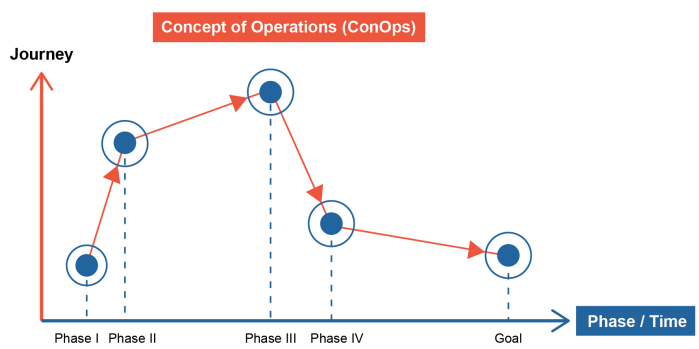
Before entering the mode of creating project ConOps, the project team needs to know the goal of the mission. Was the project intended to collect material and data from the Moon, or establish a sustainable business around the Moon and the Earth? The answer is to build solar power energy transmission system in this study. The clarified project mission set a cornerstone for accelerating the rest of the process. The blue dot in Figure 3 indicated the project's end goal.



[Figure 3] Set up the Right Goal for the Project

Step 2 - Identify the Key Phases

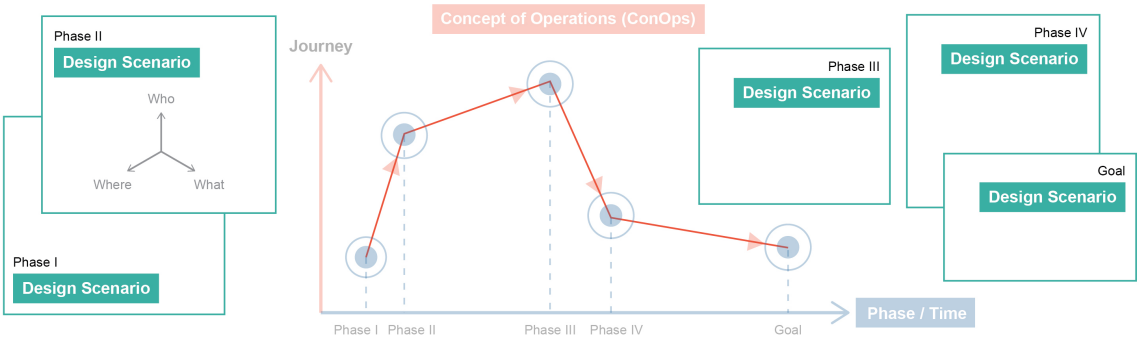
Once the project goal was well-established and clarified, the next question was how to achieve the project goal by breaking it down into key phases. It needed to take the critical elements including estimated lunch/travel/arrival time, resources, and approximate locations into consideration and arrange these key phases in sequence. The project also needed to evaluate the backup plan in case of other unpredictable factors. Figure 4 demonstrated the simplified version with four phases to achieve the project goal.



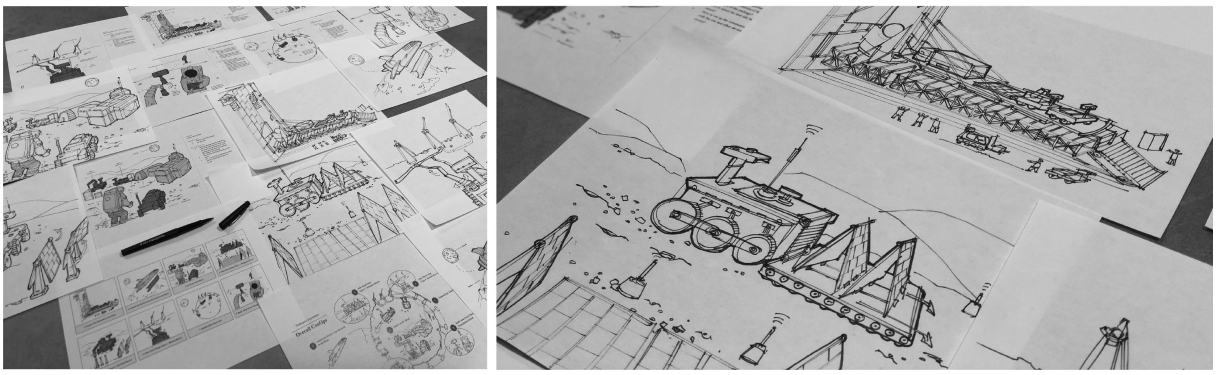
[Figure 4] Identify the Key Stages of the Project Journey

Step 3 - Visualize the Concept

With a clear goal and key phases all set, the next step for the project was to connect all the key phases together in sequence by visualizing the journey of the project. What could be the possible scenario in each key phase, including three recommended criteria to evaluate: the who, the where and the what to help envision the future scenario? It was an innovative part of the process by adding a design scenario tool to the project ConOps. It needed not only to reconsider the scope of the project in terms of the time frame, the logistics, and location in the mission but also to take people's interaction, behavior, the extreme environment condition, the relevant equipment and other elements into detailed consideration. A format to interpret ConOps, scenario visualization was an important and powerful tool to efficiently improve internal communication with ease and at a low cost. The case study presented the selected phases by illustrating the key components (Figure 6) including spacecraft, three types of rovers, astronaut and integrating them into the project ConOps. The green boxes shown in Figure 5 were the space for scenario visualizing connected to phases accordingly.



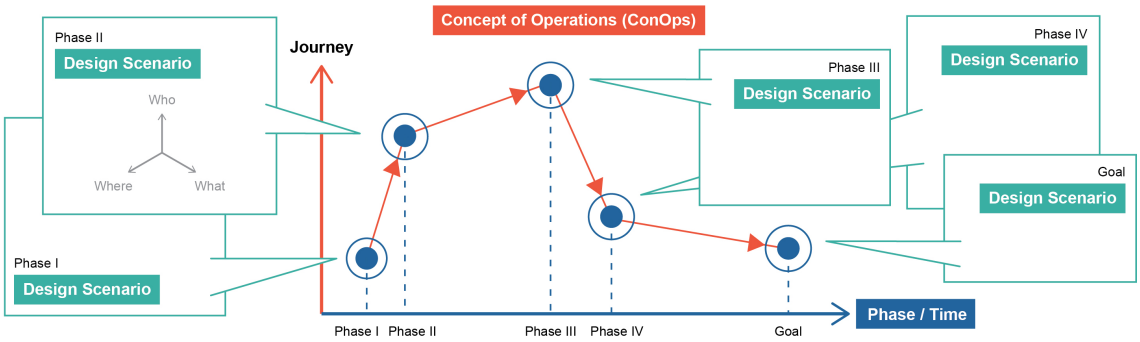
[Figure 5] Visualize the Overall ConOps for the Purpose of Communication



[Figure 6] Visualiz the Key Components and Integreated into the Proejct ConOps for the Purpose of Communication

Step 4 - Map out Design Scenario Connected with Key Phases in ConOps

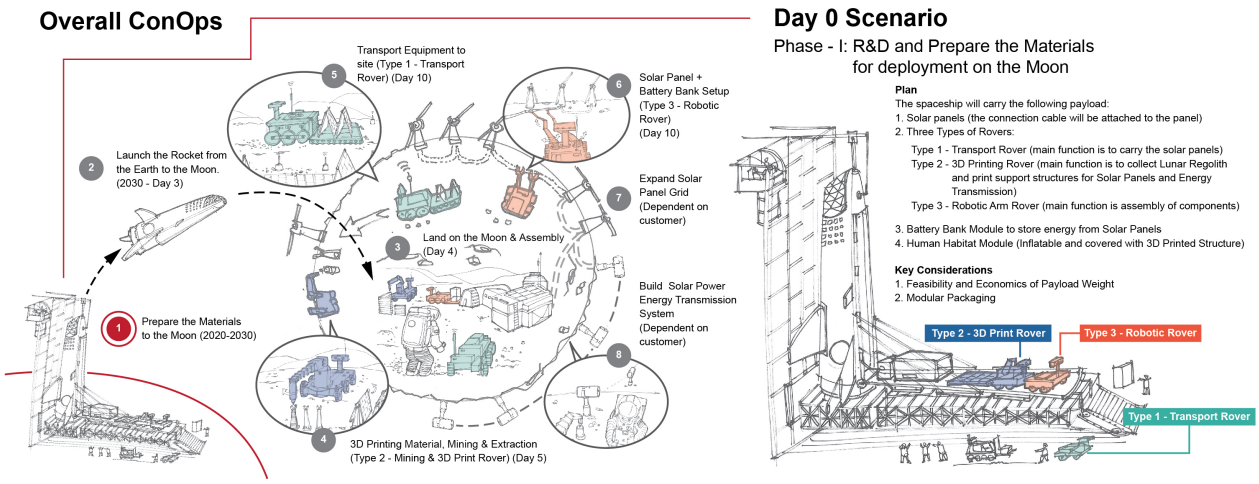
Step 4 was the highlight of the process by connecting the design scenario with the key phases in the project ConOps. The project ConOps served to illustrate the overall mission in terms of the structure and the sequence, whereas the design scenario was to play a significant role in forecasting the possibility of the future, condition, and interaction between people (astronaut, NASA), environment and objects (equipment, spacecraft) in each key phase. Design scenario was a helpful creative tool for the internal team and key stakeholders to utilize in the mission. The simplified diagram presented in Figure 7 conveyed the concept and the relationship of ConOps, key phases, and design scenarios.



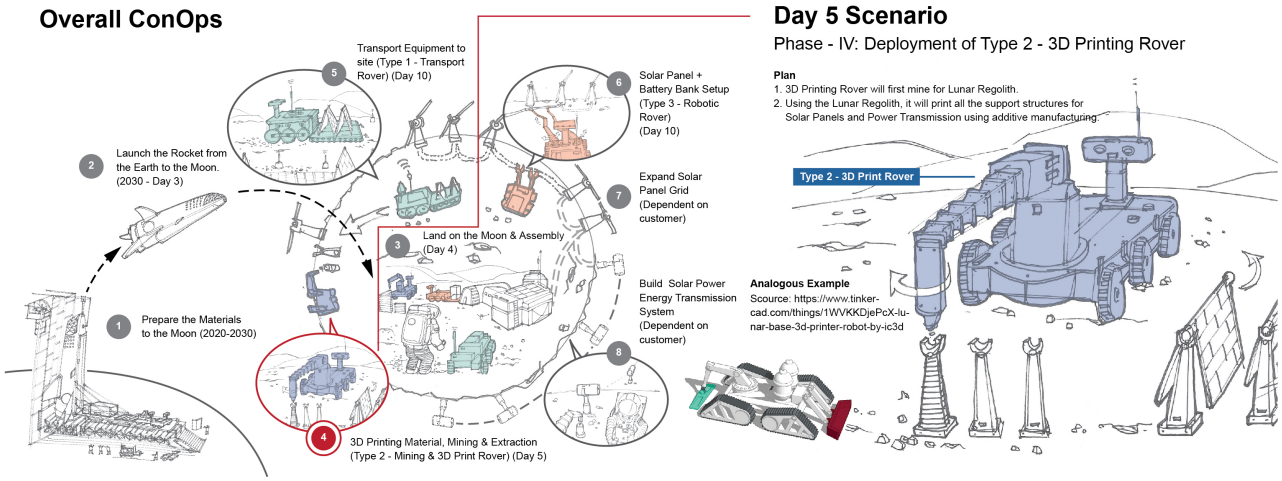
[Figure 7] Mapping out Design Scenario Merged with ConOps

3.3 Design Highlight

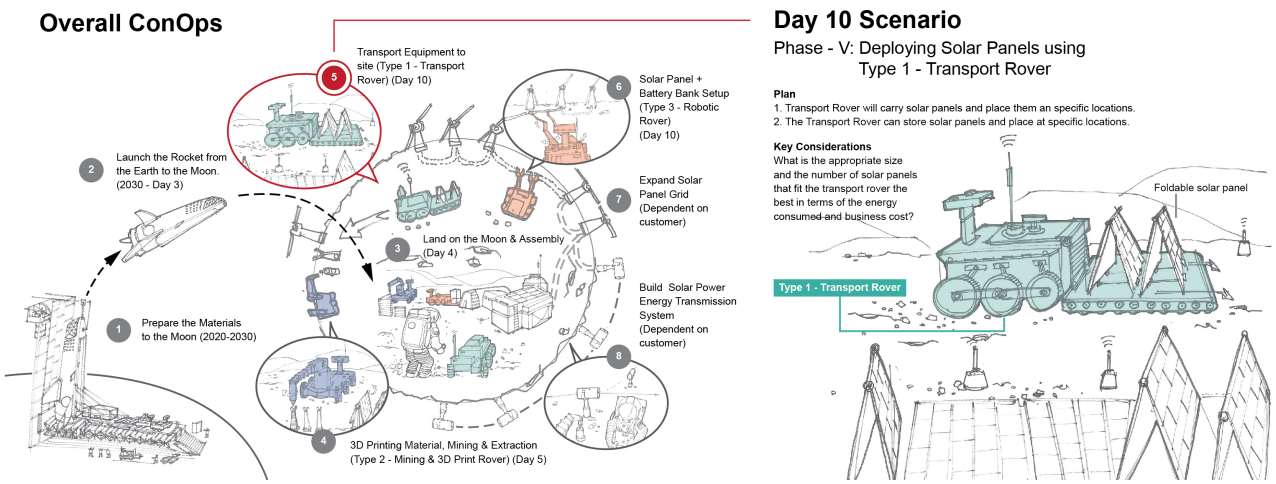
The following three images were selected from the commercial cislunar space development project to present the idea of using ConOps as a main backbone structure and adding design scenario to each stage in the project.



[Figure 8] Phase I: R&D and Preparing the Materials for Deployment on the Moon



[Figure 9] Phase IV: Deployment of Type 2 - 3D-Printed Rover



[Figure 10] Phase V: Deploying Solar Panels Using Type 1 - Transport Rover

4. Summary and Suggestion

4.1 Key Learnings and Reflection

Task-driven Approach and Context-driven Process

ConOp was used as a tool to convey the project's mission and its scope to the key stakeholders and internal team. The topics included the project's estimated time, approximated locations, allocated resources, business model and strategy. One of its goals was to map out a blueprint to assign the tasks and sub-tasks to the internal project teams to complete the mission. In the lens of the structure of the mission, ConOp was a tool featured with a linear-yet-time-depend process driven by specific project tasks that derived from separating the goal of the mission. Whereas a design scenario was a context-driven tool, which greatly illustrated the interaction between people's behavior, equipment, and environment within each key phase of ConOps in the project. A design scenario tool served the purpose of composing a series of the storyboard to bring ConOps to life by zooming in each key phase through visuals and descriptions of the scenarios. The details of the comparison of two tools were documented in Table 1.

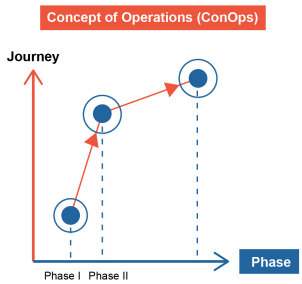
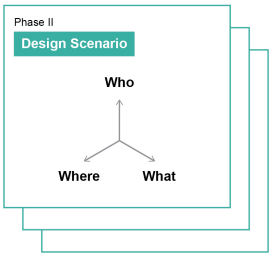
Structure-based Planning Tool and Concept-oriented Action

While applying ConOps, the sequence of the mission was a critical factor, which affected the establishment of the project mission in the lens of structure. The sequence of the project mission involved scientific research and theory, logistic, time frame, set-up of the designed equipment of the project and people (astronaut, NASA, key stakeholders). Besides, some fundamental questions needed to be considered. Take the commercial cislunar space development project as an example, where were the estimated landing spots for three types of rover on the Moon? And how did the approximated locations change between the key phrases? When was the estimated time range to connect with International Space Station? What were the instructions for controlling the rovers when landing on the Moon? In the above scenario, ConOps provided a structure-based planning tool in order to reasonably assign the right sequence of each scientific task in every key phase, whereas a design scenario was a concept-oriented action. A design scenario tool was composed of many curated design concepts to help envision the possible future setting, which raised the key question: How did the environment (where), people's behavior (who), and equipment (what) interact? In the case study, the project team also considered the following questions as an example:

- Who was the target group (astronaut, NASA, key stakeholder) in the scenario? And what was their relationship?
- Where was the estimated location in which environmental condition and required what types of scientific research tools, equipment, and process accordingly?

The above considerations serve to inform the project team to generate concrete concepts in a comprehensive way to fill the space between the key phase in project ConOps.

[Table 1] The Comparison of ConOps and Design Scenario

	ConOps	**Design Scenario**
Tool		
Purpose of the Tool	A ConOps is a tool to map out the whole project journey in the principle level to better inform the key stakeholder and internal project team the project mission in terms of the structure, the sequence, and the process in the early stage of the project.	A design scenario is a communication tool to illustrate the possible future scenario and its condition connected to each key phase in the project journey. It helps the key stakeholders and internal project teams develop empathy in the context of the mission and promote the communication in an efficient way.
Feature of the Tool	• Task-driven approach • Plan the whole picture of the project • Structure-based planning tool	• Context-driven process • Envision the possible scenario/moment connected to each key phase in ConOps • Concept-oriented action
Key Consideration	• Consider the estimated time of the mission. • Consider the approximate locations and its corresponding stages of the mission. • Plan and map out all key phases and concepts during the mission.	• Visualize the interaction between people (who), equipment (what) and its relevant environment (where). • Design the conversational-yet-provocative questions within each scenario. • Explain each concept/scenario in context.

Challenges of ConOps Explanation

A ConOps is a communication tool to present a project blueprint of how to solve a complex, multidimensional and multifaced systematic challenge step by step. In most cases, successfully articulating the intent and present the structure of the project mission merely through ConOps is still difficult. There are two aspects to understand the difficulties:

- Information Level and Fidelity
  A ConOps can be used as the project blueprint to show the mission structure and its sequence of key phases through diagram and description. Since most challenges are complex with complicated factors, one of the key considerations is how to present the right level of information with the proper extent of fidelity within a reasonable scope of the project to the audience (evaluator, key stakeholder, internal team) without information overloading and distraction.

- The Use of Language
  It has been challenging to apply ConOps to design for and present to the target audience (evaluator, key stakeholder, internal team) in the early stage of project development since the target audience is a team of experts with diverse backgrounds and from different industries. It is impossible to explain the ConOps clearly without bringing the target audience into the context of the mission by providing an immersive and simulation experience. Therefore, how to use the precise and clear language to describe the key phases of the mission, the process, the condition without overuse of jargon has become increasingly important. Especially, when the project has evolved and the project team and stakeholders have grown bigger, it becomes significantly critical to look into the question of sharing the information of ConOps and its relevant industry knowledge in a suitable and professional way.

4.2 Next Step for the Project

Integrate Design Scenario with ConOps

There are no perfect tools in the world to solve any type of challenges in the field of design and system engineering. One possible way to improve the tool and methodology was through the right curation and integration of the selected approaches. According to the research in the study, a ConOps tool was a robust backbone to structure and mapped out the future concepts and scenario generated by applying the design scenario tool. 'Systems mapping is one of the key tools of the systems thinker' (Acaroglu, 2019). In the context of the project, ConOps was viewed as a systematic mapping tool to define the various key phases of the mission. As the ConOps evolves, the system designers/the project team need to consider some critical questions e.g. What is the expected or designed lifetime for the system and its components? What environmental requirements must be met for the purpose of reaching and maintaining the best solution of the system (Slater & Snyder, 2008).

A design scenario tool is like a muscle to support the skeletal structure of the ConOps. Take the commercial cislunar space development project as an example, by integrating design scenario into ConOps, it made the overall ConOps diagram informative and the concepts and scenarios easy to relate to and understand. However, there are still many important directional questions that need to be answered, such as "Who will illustrate the design scenario and in what level of fidelity?", "How to establish a system/platform to generate a project brief for the design scenario in the context of ConOps?", "How to position a project brief in the organization?", "What type of knowledge and expertise do the design scenario team member need to equip itself with in order to achieve the goal?", "Who will be recruited in the design scenario team?" and "How does the organizational structure of the team?". The study was a preliminary discussion on curating the two tools and there was still room to experiment with and improve the seamless integration of ConOps and design scenario.

Establish Design Principles to Use Graphic

For further research, the key component to successfully integrate ConOps and design scenarios is applying the graphic and all relevant visuals properly to both tools. The graphic stands for not only scenario illustrating but also a type of visual language to assist in simplifying the content and increasing the efficiency of internal communication. Therefore, establishing a set of design principles for applying the graphic to ConOps and design scenarios was invaluable for the next step of the study. The following list of design principles was presented as an example.

- The graphic needs to accurately reflect and simplify the content of the project mission.
- The graphic needs to present the relationship between the key phases and the whole process of the project.
- The graphic needs to amplify the process of the project mission with a comprehensive approach.
- The graphic needs to articulate the selected future scenario of the system in use.
- The graphic needs to explain by itself the connection between the target group (who), equipment (what), its environment (where) and the time that the phrase starts (when).

Acknowledgements: *The DMI conference paper and the Commercial Cislunar Space Development Project can't be finished successfully without the great help and warm support from many people, friends, faculties and family. Especially thanks go to MIT Engineering Systems Laboratory: Prof. Edward F. Crawley, Dr. Yaniv Mordecai; Commercial Cislunar Space Team: John Liu, Sebastian K Hampl, Hassaam Ali; Zhou Xuan, a professional English translator, MIT Integrated Design & Management (IDM), and MIT AgeLab.*

References

Acaroglu, L. (2019, October 7). Tools for Systems Thinkers: The 6 Fundamental Concepts of Systems Thinking. *Medium*. https://medium.com/disruptive-design/tools-for-systems-thinkers-the-6-fundamental-concepts-of-systems-thinking-379cdac3dc6a

De Weck, O. L., Roos, D., & Magee, C. L. (2016). *Engineering Systems: Meeting Human Needs in a Complex Technological World*. MIT PRESS.

DOD Dictionary of Military and Associated Terms. (2010).

Fairley, R. E., Thayer, R. H., & Bjorke, P. (1994). The concept of operations: The bridge from operational requirements to technical specifications. *Proceedings of IEEE International Conference on Requirements Engineering*, 40–47. https://doi.org/10.1109/ICRE.1994.292405

Ferronato, P. B., & Ruecker, S. (2017). *Strategic Design, Scenarios and Anticipatory Systems*. 7.

Fulton Suri, J., & Marsh, M. (2000). Scenario building as an ergonomics method in consumer product design. *Applied Ergonomics*, *31*(2), 151–157. https://doi.org/10.1016/S0003-6870(99)00035-6

Interaction Design Foundation. (2020, April 15). Design Scenarios—Communicating the Small Steps in the User Experience. *The Interaction Design Foundation*. https://www.interaction-design.org/literature/article/design-scenarios-communicating-the-small-steps-in-the-user-experience

Larson, W. J., Kirkpatrick, D. H., Sellers, J. J., Thomas, L. D., & Verma, D. (Eds.). (2009). *Applied Space Systems Engineering*. McGraw-Hill Learning Solutions.

Madsen, S., & Nielsen, L. (2010). Exploring Persona-Scenarios—Using Storytelling to Create Design Ideas. In D. Katre, R. Orngreen, P. Yammiyavar, & T. Clemmensen (Eds.), *Human Work Interaction Design: Usability in Social, Cultural and Organizational Contexts* (Vol. 316, pp. 57–66). Springer Berlin Heidelberg. https://doi.org/10.1007/978-3-642-11762-6_5

McGraw, K. L., & Harbison, K. (1997). *User-centered requirements: The scenario-based engineering process*. Lawrence Erlbaum Associates.

Nardi, B. A. (1992). The use of scenarios in design. *ACM SIGCHI Bulletin*, *24*(4), 13–14. https://doi.org/10.1145/142167.142171

NASA Systems Engineering Handbook. (2007). National Aeronautics and Space Administration.

Owens, C. V. (2017). Tailoring a ConOps for NASA LSP Integrated Operations. *INCOSE International Symposium*, *27*(1), 1647–1662. https://doi.org/10.1002/j.2334-5837.2017.00453.x

Shiamzu, K., & Ohkami, Y. (2011). The 2x2 Requirement Chart for ConOps Development to Optimize both Cost of Study and Operation Periods. *2011 Proceedings of IEEE Southeastcon*, 345–350. https://doi.org/10.1109/SECON.2011.5752963

Slater, M., & Snyder, J. (2008). Connect or terminate: How CONOPS drives design of sub-sea network systems. *OCEANS 2008*, 1–6. https://doi.org/10.1109/OCEANS.2008.5152020

Swanson, E. H. (2016). Building Design Scenarios the Way Life Is Lived: The Contextual-Scenario Toolkit. In A. Marcus (Ed.), *Design, User Experience, and Usability: Design Thinking and Methods* (Vol. 9746, pp. 344–355). Springer International Publishing. https://doi.org/10.1007/978-3-319-40409-7_33

Walden, D. D., Roedler, G. J., Forsberg, K., Hamelin, R. D., Shortell, T. M., & International Council on Systems Engineering (Eds.). (2015). *Systems engineering handbook: A guide for system life cycle processes and activities* (Fourth edition). Wiley.