

Conceptual Modeling of Human Processes in a Lunar Systems Architecture

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ABSTRACT

This paper presents a case for supporting the architecting of a conceptual system and its associated human activity with an analytical model. The human activity is treated as a peer to the system's operation using Object Process Methodology (OPM) and uses manned Lunar operations as an example. There is a brief discussion of architecture, architecting, and systems architecture, to set the context for the terminology used to present the modeling context. This early stage analytical modeling in a systems conceptual definition provides a comprehensive means for evaluation of the design for functions it is required to support. The models also provide a consistent basis for the more complex models used later in the systems implementation. Systems modeling is an accepted practice for describing the complex interactions in and among systems, however, the modeling of human activity in conjunction with systems is less well developed. The Systems Modeling Language (SysML) is an accepted systems modeling capability that requires up to seven types of diagrams to represent a system and its operation. OPM is a more recent development in systems modeling and, in contrast to other methods, has a single diagramming methodology which can represent structure, dynamics and relationships. The OPM naturally represents human activity as an agent interacting with a system or as an object within the system. The NASA Lunar Architecture and a functional analysis of an Apollo based Lunar rover are used as a basis for the OPM models of crew activities. Models for humans as agents for a system, as well as a part of a system, are presented with their peer text descriptions.

INTRODUCTION

The use of analytical modeling of human activities will be explored as an additional tool to support human related architectural systems design. The role of analytical modeling in this context is to document the functionality of the conceptual design and thus augment the variety of ways the system described, bringing a systems engineering component into the design process. In the process of applying the analytical modeling the modeler may have additional insights into his design as is typical

with other tools which record a design and, as a result of the insights, modify the design. The aspect of human activity concerning this modeling has no social component, but simply to represent the interaction of the human with the system activity. There is no aspect of human - system simulation, although the analytical model may be stepped through the system activities to verify system functionality. The architectural specialization focused on in this paper is space architecture, the products of which are human rated entities which ultimately would function as a system in space. Space architecture presents a different architecture - engineering continuum of practice than that for which a civil architect is trained. A design in the space architecture systems engineering continuum becomes part of the aerospace product development process as opposed to the civil process. The major aerospace clients such as NASA, ESA, or JAXA, have well established program and system engineering standards which are quite different from those of a civil engineering firm. As a consequence, the space architect should present his design in a form that is consistent with it being able to migrate easily into a systems engineering environment. Analytical modeling augments this capability.

Establishing the definitions of the terms system, architecture, and systems architecture is necessary to ensure that architects and aerospace engineers have a common reference for terms in this paper. A system which is the product of the somewhat more specialized area of architecture, space architecture, will necessarily be a human rated aerospace system. The ultimate human related system is the human himself, requiring that any definition of a system must include natural systems along with artificial systems. Dori [2002a] postulates that systems "exhibit three major aspects: function (what these systems do), structure (how they are constructed), and behavior (how they change over time)". The definition of a system in Maier and Rechtin [2000] recognizes only structure and function, not behavior: "System: a set of different elements so connected or related as to perform a unique function not performed by the elements alone." It will be shown later that behavior as a system process is a necessary component of a system description within OPM. A more

terse, object oriented definition is given by Embley et al. [1992] as: "a system is a group of interacting objects." The "compact" definition given by Dori [2002a] recognizes only the functional component of the major aspects of a system: "A system is an object that carries out or supports a significant function". These definitions all have in common the word function, and can support a human system. Any of these definitions are adequate from an aerospace systems engineering standpoint which focuses on functional requirements in the conceptual design phase of a system.

The term architecture, as related to the practice thereof, will not be addressed in this paper other than to offer analytical modeling as a beneficial addition to the conceptual design process of space architecture. The definition of systems related architecture seems to be somewhat contentious based upon Maier and Rechtin [2000] devoting an appendix to defining the word and related terms. Their definition is: Architecture: The structure (in terms of components, connections, and constraints) of a product, process or element. This definition does not explicitly relate it to a system. As this paper addresses space architecture and systems, a definition that introduces systems would be more

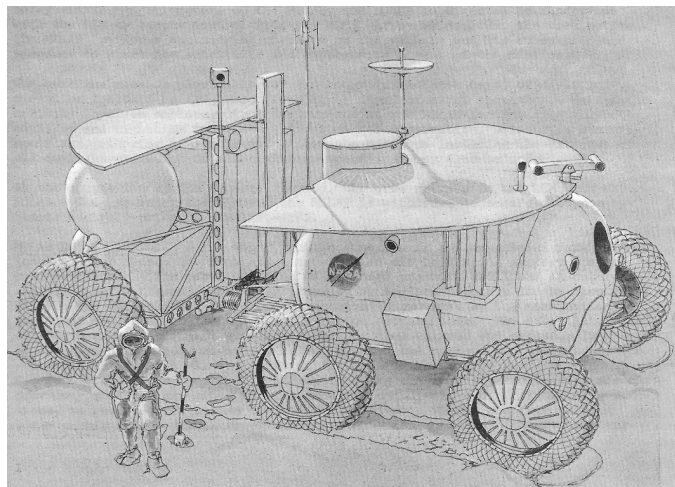


Figure 1 Conceptual Drawing of mobile laboratory (MOLAB)

appropriate, the IEEE's Recommended Practice for Architectural Description, P1471, definition for architecture is: "Architecture: The fundamental organization of a system embodied in its components, their relationships to each other and to the environment and the principles guiding its design and evolution". The International Council on Systems Engineering (INCOSE) adopted this definition: Systems Architecture: The fundamental and unifying system structure defined in terms of system elements, interfaces, processes, constraints, and behaviors. The INCOSE definition would seem to fit the needs of this paper, although the inclusion of the idea of an environment for a system is useful. One can summarize these definitions for this

paper's needs as: A space system with a human component, interacting with other systems which can be described by a systems architecture.

Space-based systems use analytical modeling extensively in the design, testing, and operation in their development. An analytical model represents a system by means of equations, graphical symbols, or other forms of technical representation that convey the structure and functionality of a system. This type of representation is not that which would be found as a result of digital design activities which are typically produced by a computer aided design (CAD) program. In this paper, the term applies to the diagrammatical / textual representation of a system. The analytic modeling will be applied to an element of a lunar architecture as developed by NASA [2005], which is a lunar rover based upon an Apollo Program development in Boeing [1965] called Mobile Laboratory (MOLAB), Figure 1. The architectural phase of a system design has traditionally used three dimensional mockups and high level analytical trade studies of the intended design and more recently have used computer based models to represent the conceptual design. The use of architectural models has traditionally bridged the early phases between the architectural - engineering process, conveying the architect's implementation of the functionality desired by the client. This paper will examine the use of analytical systems modeling in an analogous manner, including the incorporation of models of human activity, to provide an analytical model bridge between a space system conceptual design and design implementation.

Conceptual Analytical Modeling

COMMUNICATING THE SYSTEM'S CHARACTERISTICS - With the terms such as systems and architecture addressed, the process of conceiving, designing, and producing a system needs to be examined. The application of architecture and engineering is presented as a continuum of practice between those two poles in Maier and Rechtin [2000]. A component of the continuum, "Methods" describes architects as tending to use synthesis and heuristics while engineers use equations and analysis. This paper will argue for moving elements of engineering in the continuum into the sphere of architecting. A principle element of this architecting process is conceptualization. Dori [2002b] describes the conceptualization process as an activity that has always relied on some type of model. Conceptual models informed the clients and served as a means of communicating the characteristics of the design. Over time the models have become more sophisticated, graduating from sketches and mockups to computer based models and animations. Conceptual analytic models are a representation of the system architecture and are usually one or more diagrams based on an associated methodology. This paper will

address a form of conceptual analytic modeling which is descriptive of both human activities and system processes.

ABSTRACTION OF COMPLEXITY - The modeling of a conceptual design by an architect is a means of abstracting the complexity in the design space. Designs associated with humans in space, are very complex, including elements such as communications, harsh environments, resources and human factors. The abstraction of complexity by modeling allows the architect to communicate with the client and other stakeholders at a high level while being able to decompose the design as necessary to address specific details. As the models evolve, they form a means to communicate and sometimes integrate directly with the following phases of engineering design. In the same sense, analytical models can abstract complexity and provide a path to subsequent phases of engineering

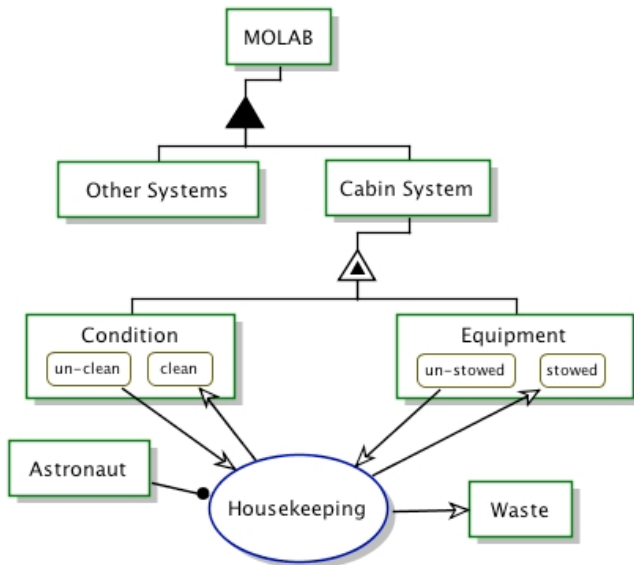


Figure 2 'The Object Process Diagram (OPD) of housekeeping function

development. The use of analytical modeling by the space architect as an additional tool in his practice, provides a natural interface to the models used in the systems engineering activities of aerospace system development.

HUMAN SYSTEMS INTEGRATION - The need to model systems and architectures is well established, but the need to model human activities in the same context is less well developed. The DOD Architecture Framework, DOD [2004], provides a rationale for the "Human Systems Integration" (HSI) into a system architecture. The addressing of HSI during the conceptual phase of a design can take large steps toward reducing the total ownership costs and more effectively integrate the performance and efficiency of humans within the systems, DOD [2004]. "Over the lifecycle of the system,

or system of systems, humans within the system are consistently the most costly resource." The range of roles for human activities interacting with hardware and software include those of a passive monitor, active initiator, reporter, planner, and decision maker. An analytical modeling methodology suitable for representing human activity should accommodate different roles for the same person.

SYSTEM MODELING LANGUAGES - The modeling of systems as a whole should be contrasted to those specialized languages which focus on a particular discipline, such as structures, thermal analysis, and communications. Another point of distinction is that much of the system modeling methodology work in the last 10-15 years has been focused on information systems which has caused them to be less suitable for space systems. Some of these are extensible to systems in general, but with modifications that add to their complexity, rather than simplify the languages. The final consideration for selection of a language is the degree to which it accommodates the representation to human activities. There are several system modeling languages that could be considered, but only two will be addressed. The languages will only be compared to the point of contrasting the relevant features needed to support the rationale for the selection of the OPM methodology for use in this paper.

Systems Modeling Language (SysML) - This modeling language is an adoption of the information systems oriented Unified Modeling Language (UML) to systems engineering, by the Object Management Group and INCOSE. SysML uses nine diagram types of which seven are taken directly from the fourteen diagrams of UML. The reduction in the number of diagrams improves the ability to learn SysML over UML. SysML is the only proposed standards-based systems modeling language and though relatively new, will likely be widely used due to the popularity of UML. The human activity in SysML is represented primarily through use cases, sequence, and activity diagrams. The use case diagram presents a static view of system functionality by actors associated with use cases. The actors represent anything in the systems environment (external to the system) which interacts with the system. Thus an actor could be a system user or another system or device. A use case diagram can depict relationships between use cases and actors, but the primary information is a textual description of the functionality represented by the use case. The activity diagram presents a workflow view of system activities, which may model a use case as an activity. The activity diagrams provide a temporal flow which is not available in a use case. The activity can be considered to be a human task. Class, activity and sequence diagrams must be kept consistent to accurately represent the a process. The three diagrams require a significant portion of the potential one hundred some symbols used in SysML.

Object Process Methodology (OPM) - The OPM is a more recent and consequently less widely accepted modeling language. This methodology is unique in that

consume or yield a state object. Here the links indicate that the housekeeping process changes the state of condition from unclean to clean and that of equipment from unstowed to stowed. The link connecting the astronaut to the process is represents the astronaut as a human agent who enables the process but is not changed by it. The non-human version of the enabler link is an open circle. The open-headed arrow link from a process to an object indicates that the process has created that object.

MOLAB is physical.
MOLAB consists of Cabin System and Other Systems.
Cabin System is physical.
Cabin System exhibits Condition and Equipment.
Condition is physical.
Condition can be un-clean or clean.
Equipment is physical.
Equipment can be stowed or un-stowed.
Other Systems is physical.
Astronaut is physical.
Astronaut handles Housekeeping.
Waste is physical.
Housekeeping is physical.
Housekeeping changes Equipment from un-stowed to stowed and Condition from un-clean to clean.
Housekeeping yields Waste.

A corresponding textual description called the object process language (OPL) is produced concurrently with the OPD as a series of sentences forming a paragraph, as shown in Figure 3. Because the OPL is a

fully descriptive textual reflection of the OPD, it is suitable for parsing for other analysis purposes such as providing a summary of human activity by examining the agent links and human objects. The OPL creates a quick way to check the construction of the model in an OPD. If the sentence or phrase doesn't reflect the system, then the model needs to be adjusted. The language is easy enough for a stakeholder or customer to read and understand, thus providing a concise, descriptive means of communication.

The experience base of SysML is not large enough yet to understand its acceptance into the systems engineering community. The SysML heritage from UML will create the same problems experienced by UML users in developing an integrated, consistent model over numerous diagrams Dori [2002b]. The use of OPM as the analytical modeling methodology for this paper is based on the following rationale:

- OPM uses one diagram type while SysML uses nine.
- OPM is bimodal with the text description providing a cognitive check of the model.
- OPM provides a direct representation of human activity integrated with the system description.
- The OPM is primarily a system description methodology as opposed to an information systems methodology adopted to system description methodology.

The Role of Functionality in Design Evaluation

Now that terminology has largely been addressed and a modeling language introduced, another aspect of conceptual design, concerning functionality, should be addressed. The concerns here are how the functionality the design exhibits is represented and how it is evaluated. System functionality is traditionally a large

Figure 3 'The Object Process Language (OPL) of the housekeeping function

it has only one diagrammatic representation which conveys both the structure and behavior of a system. OPM uses a much smaller set of symbols, approximately thirty, than SysML. It is termed a concurrent bimodal language because the diagram symbols and links have a textual counterpart which describes the system in semantically equivalent text sentences. The primary "things" in an OPM diagram are objects and processes, with links and associations which relate to structure and activity. The downward arrangement of process symbols depicts the flow of time. The OPM counterpart to the SysML actor is an agent, human or non-human who interacts with the system as enabler that controls a process. An example of an object process diagram (OPD) is illustrated in Figure 2 for a MOLAB housekeeping function. The OPD is the visual product of OPM that describes the structure and/or behavior of as system. The rectangles are objects that can be either physical or informatinal (a generalization of data, information without reference to its physical manifestation); in this case they are all physical as evidenced by the shadow around the rectangle. The diagram is topped by the MOLAB, which is shown to be an aggregation of systems as denoted by the black triangle below it. The triangle within a triangle indicates that the cabin system has at least two characteristics, or attributes: condition and equipment. The rounded rectangles within the characteristic objects are their possible states. The cabin condition can be unclean or clean and the equipment can be unstowed or stowed. The oval represents a process which is an activity that only exists to transform an object, change the state of an object, or create or consume an object. The process is connected to the surrounding entities by links which describe their relationships. The open arrow-headed link which connects the process and a state is said to

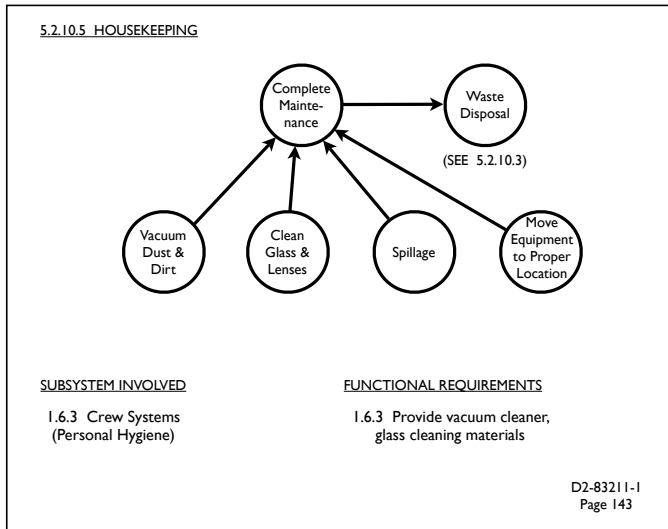


Figure 4 - MOLAB housekeeping functional flow diagram

portion of the discussions between the system architect and the client/stakeholder. In the aerospace domain, functions are embodied in requirement documents, tracked and allocated with sophisticated requirements management software. Even with a growing movement within the systems engineering standards community for model based systems engineering (MBSE), Baker et al. [2007], Estefan [2007] processes seem to continue starting with text based functional requirements, then allocating those requirements further down the system hierarchy. The textual mode of OPM offers a means for deriving requirements from a model forming a model led MBSE requirements process. The OPM models identify functions naturally, so that developing OPM models from concept documents would lead to the identification of functional requirements. The derivation might not be necessary if the OPL sentences were treated as requirements and fed directly into OPL accommodating requirements tracking software. At a minimum, OPM's functional identification capability offers the bi-directional capability to derive functional requirements from a model and to assess a model for fulfilling given functional requirements. This OPM capability is facilitated by a template proposed by Soderborg et al. [2003] which facilitates examining an OPM model for a particular arrangement of graphical elements inherent in the expression of a function. An summary of this OPM functional representation capability is given in Appendix A. This analytical model based incorporation and evaluation of functionality is objective and can be enhanced by post model computer processing techniques for examining the OPDs and OPLs, enabling the reporting of all human related activities in a system model.

5.0 Mission Functions

5.2 Specific Mission Functions

5.2.10 Crew Maintenance - Associated Activities

5.2.10.5 Housekeeping

Lunar Systems Architecture

NASA uses the term Lunar Architecture [4] to describe the product of its analysis and planning that was performed to develop a mission concept for lunar exploration under the aegis of the Constellation Program which has lunar and Mars exploration within its charter. This paper will use this material for a representative lunar infrastructure. The use of the term architecture is consistent with that which has been discussed in this paper, however the large number of systems involved suggests that "lunar systems architecture" would be a more appropriate title for a model based architecture. It is important for this larger view to be taken to support this analysis because of the diversity of systems, some Earth based, needed to enable human lunar activity. A lunar systems architecture modeled with OPM is presented in Appendix B. This topdown modeling approach allows the assessment of human activity as an enabler on an intersystems basis. Conversely, the model delineates what systems are required for human activity. This paper, as previously stated, will use a manned mobility vehicle as a basis for detailed modeling of human activity. The technical details are taken from the Apollo Logistics Support System (ALSS) MOLAB Functional Analysis [5]. The functional data in the report is presented as functional data flow diagrams and as text based functional requirements derived from the analysis of the diagrams.

Human Process Modeling

The predominant role of a crew member in a lunar architecture is that of an enabler or agent of change. The previous OPM example of a simple crew systems housekeeping function from the MOLAB Functional Analysis will be used

to elaborate on the modeling of a human enabler. The MOLAB document used a type of analysis called "functional network analysis", an example of which is shown for the housekeeping function in Figure 4. The main components are the functional flow diagram and the text based derived functional requirements allocated to the subsystems. The OPD of the housekeeping function in Figure 2 is the statement for the functional need for housekeeping and of what needs to be accomplished without indicating how it should be accomplished. The comparable statement in Figure 4 is the caption in the upper left of the diagram. The specific functional breakdown leading to the housekeeping function is shown in the box above. For the OPD of housekeeping to be placed in a similar functional context, it would need to be placed within a process for a mission OPD. An OPD diagram, equivalent to Figure 4, which can be considered the implementation of the housekeeping function, is presented in Figure 5. This form of an OPD is the "how" portion of a Soderborg Template. The "how" portion of the template presents the implementation of the function with a specialization

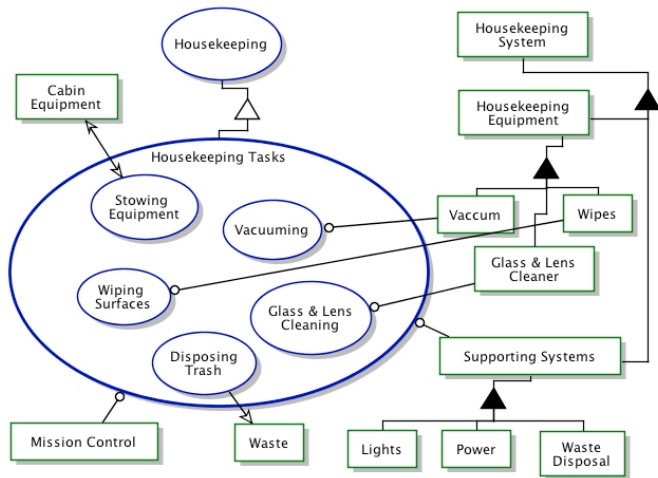


Figure 5 'Implementation' Object Process Diagram (OPD) for the housekeeping function

of the housekeeping process, agents, and objects of the MOLAB's existing systems and the system being implemented.

The sub-functions of the functional flow diagram are represented as sub-processes. The use of the OPM concept of enablers to a process provides a more explicit representation to the implementation, such as required light and power. The bimodal aspect of OPM is illustrated with the OPL from the housekeeping implementation OPD shown in Figure 6. The simple sentences provide a concise, alternative description of the modeled system, enabling one to check their diagram by reading the text description.

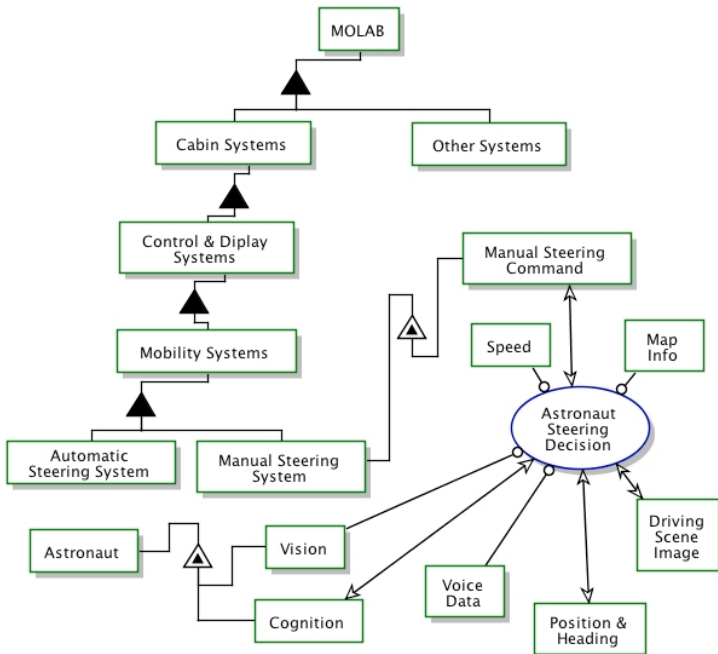
The previous example illustrated the role of a human as an enabler to a system, as opposed to the other role of a human being as an object within a system. In the later type of role, the attributes and state of the human object play a larger part in representing the human process. The MOLAB manual steering sub-function will be used as an OPM example of a human as an integral component of a system. The OPM representation is presented as a simple functional "what" model in Figure 7. The astronaut steering decision process involves him taking a variety of inputs about the state of the steering direction, making a cognitive decision about the required direction, and physically commanding the needed

correction. The details of how the cognitive processing and the manual command are implemented are unstated within the steering decision process. The astronaut characteristics of vision and cognition are the primary human attributes associated with this function. Vision in this case is an enabler rather than an agent association. The cognition attribute is associated with the process as a link that declares it to 'affect' or interact with the steering process. The values of the attributes, ergonomics, and responses needed for the task would be found in a reference such as the Constellation Program Human Systems Integration Requirements Baseline NASA [2006]. The ODL of the steering OPD is

Housekeeping System is physical.
 Housekeeping System consists of Supporting Systems and Housekeeping Equipment.
 Supporting Systems is physical.
 Supporting Systems consists of Lights, Power, and Waste Disposal.
 Lights is physical.
 Power is physical.
 Waste Disposal is physical.
 Housekeeping Equipment is physical.
 Housekeeping Equipment consists of Vaccum, Wipes, and Glass & Lens Cleaner.
 Vaccum is physical.
 Wipes is physical.
 Glass & Lens Cleaner is physical.
 Mission Control is physical.
 Waste is physical.
 Cabin Equipment is physical.
 Housekeeping is physical.
 Housekeeping Tasks is physical.
 Housekeeping Tasks is Housekeeping.
 Housekeeping Tasks consists of Housekeeping, Stowing Equipment, Vacuuming, Wiping Surfaces, Glass & Lens Cleaning, and Disposing Trash.
 Housekeeping Tasks requires Mission Control and Supporting Systems.
 Housekeeping Tasks zooms into Stowing Equipment, Vacuuming, Wiping Surfaces, Glass & Lens Cleaning, and Disposing Trash.
 Stowing Equipment is physical.
 Stowing Equipment affects Cabin Equipment.
 Vacuuming is physical.
 Vacuuming requires Vaccum.
 Wiping Surfaces is physical.
 Wiping Surfaces requires Wipes.
 Glass & Lens Cleaning is physical.
 Glass & Lens Cleaning requires Glass & Lens Cleaner.
 Disposing Trash is physical.
 Disposing Trash yields Waste.

Figure 6 Object Process Language (ODL) for implementation of the housekeeping function

presented in Figure 8. The readability of an ODL is exemplified by a sentence from Figure 8: "Astronaut Steering Decision requires Voice Data, Map Info,



space architect must decide whether to develop the modeling skills or obtain the analysis from an outside party. The outcome of either choice is a more rigorous conceptual design gained through the consideration of the model of a system and its processes.

Conclusions

The use of analytical models to describe a space architectural systems conceptual design provides precursor models for the systems engineering needed for development and is consistent with MBSE's use of models early in a design process. MBSE is not yet widely adopted but systems engineering trends are evident in that direction as evidenced by the migration from structured techniques to object oriented methodology and the earlier introduction of model based system simulation.

The OPM offers a simpler modeling methodology that is currently available for the representation of human processes interacting with systems. The SysML requires two to three interrelated diagrams which must be kept consistent, as opposed to one for OPM. SysML requires many more symbols to represent the same level of activities than does OPM.

The utilization of OPM models in the representation of conceptual architectural designs objectively documents the functionality of the design. Analytical modeling does not express the spatial quality and the many other intrinsic aspects of a conceptual design that an architect must deal with, its simply offers a means of recording the structure and functionality of the design. A conceptual design may be documented by orthogonal views, perspectives, animations, utility diagrams, and now, system functionality, by means of analytical modeling.

Figure 7 Object Process Diagram (OPD) for MOLAB steering function

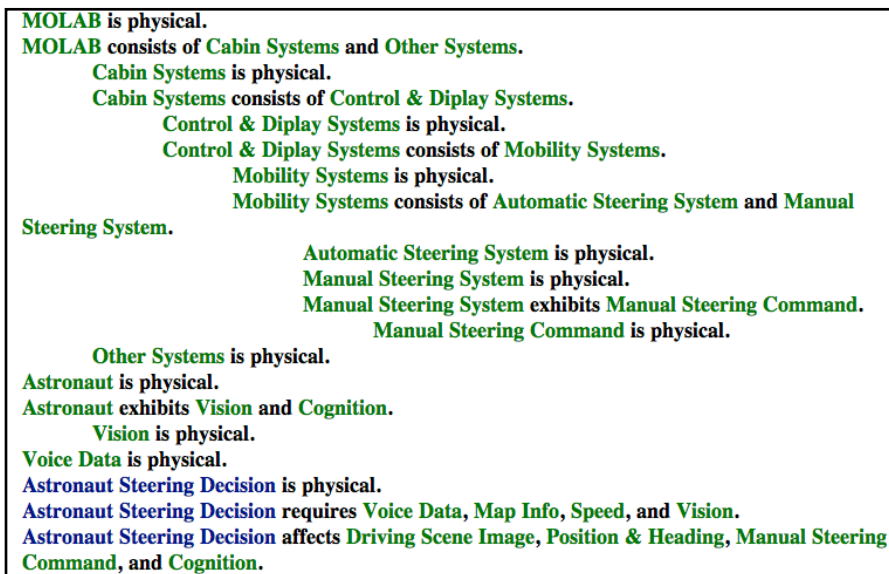


Figure 8 Object Process Language (OPL) for MOLAB steering function

Speed, and Vision.”.

With OPM introduced as a methodology for representing human activities, the focus returns to the relevance of this to the practice of conceptual space architecture design. The benefits of producing an analytical model in support of a conceptual design pivot on the clients/stakeholders relationship to, and the prospect for the design to evolve within, the aerospace community. The rigor of the analytical model will contribute to the maturity of an aerospace product ready to be integrated into the systems engineering process. On a personal level the

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ABBREVIATIONS

ALSS - Apollo Logistics Support System. An augmentation of Apollo mission which would enable the delivery of supplies and equipment for extended lunar visits.

DOD - Department of Defense.

ESA - European Space Agency.

HSI - Human Systems Integration. The engineering discipline for accommodating humans into systems design and operations.

IEEE - Institute of Electrical and Electronic Engineers.

INCOSE - International Council on Systems Engineering.

LSA - Lunar Systems Architecture. The fundamental and unifying lunar systems structure defined with system elements, interfaces, processes, constraints, and behaviors.

MBSE - Model Based Systems Engineering. The collection of related processes, methods, and tools used to support the discipline of systems engineering in a "model-based" or "model-driven" context.

MOLAB - Mobile Laboratory. A lunar rover designed for the ALSS Project.

JAXA - Japanese Aerospace Exploration Agency

NASA - National Aeronautics and Space Agency

OPM - Object Process Methodology. A holistic, integrated approach to the study and development of systems, integrating object-oriented and process-oriented paradigms into a single frame of reference.

OPD - Object Process Diagram. The visual formalism of OPM that describes graphically the structure and/or behavior of the system or part thereof.

OPL - Object Process Language. The equivalent textual counterpart of the graphic OPM system specification which describes the system in a subset of natural English.

SysML - Systems Modeling Language. A domain specific language for systems engineering defined as an extension of a subset of the UML.

UML - Unified Modeling Language. In the field of software engineering, a standardized visual specification language for object modeling. UML is a general-purpose modeling language that includes a graphical notation used to create an abstract model of a system, referred to as a UML model.

APPENDIX A. AN OPM Template for Representing Functions

The OPM functional template, Figure A-1, developed in Soderborg et al. [2003] presents a simple means of modeling the statement of a function and the implementation of that function. The definition of function in OPM is: "An attribute of object that describes the rationale behind its existence, the intent for which it was built, the purpose for which it exists, the goal it serves, or the set of phenomena or behaviors it exhibits." This definition does not include any aspect of how the object operates, just what it should do and why. The use of the words intent, purpose, goal, and behavior seems at odds with the sparse portion of the diagram for the "what" of a function. An example shown in Figure A-2 illustrates how these terms can be embodied in a functional OPD structure.

The intent of specifying the functionality of the rover concerning range is conveyed by a un-refueled range attribute. The functionality is qualified by the nature of the attribute: un-refueled. The goal is to start a traverse with a maximum range and end it with a reserve range while carrying a crew of two and performing Sortie A activities. There is nothing in this part of the diagram

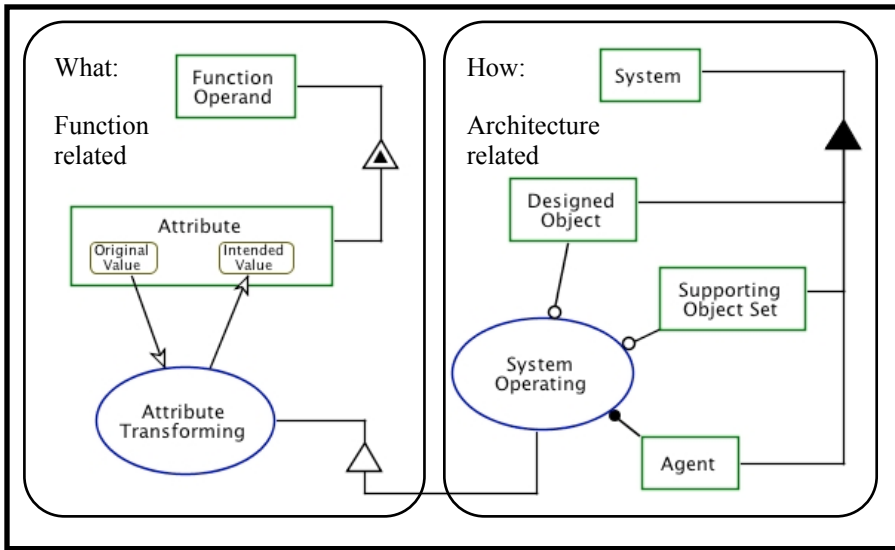


Figure A-1 The SoderBorg functional OPD template

about how this maximum range and reserve range should be achieved.

The implementation of this functionality would be addressed in the architecture portion of the OPD by a specialization of the Max Range Traversing and system/subsystem objects which would provide the required capability. The implementation can be viewed as the functional allocation to rover systems /subsystems which in turn would specify the functionality to implement. The allocation would be apportioned between the systems/subsystems implementing the required design features and those that are in a supporting role. The result on the “how” side is a specification of how the system operates to achieve the function and its associated system structure.

Appendix B. A Lunar Systems Architecture Model

The OPM model of a Lunar Systems Architecture (LSA) is an architecture framework which describes the elements and processes associated with operations near and on the Moon. The LSA was developed to provide a context for the development of the human process models in this paper and should be considered a sketch of what a complete, comprehensive LSA might be. There are areas of the LSA that haven't been developed due to the focus of this paper.

The term architectural framework is applied to the LSA to imply that any LSA-like description should be a standard for system architectural description. This is based upon the definition by Maier and Rechtin [2000] of an architectural framework as a standard for describing architectures. The fact that the exploration of the Moon, asteroids, and Mars will take many years and that there will be many systems involved, suggests that a unified description be created to insure interoperability and

smooth transitions between programs. This unified method of description should also be based upon some accepted standard so as not to reinvent things. The LSA architectural framework is based upon the IEEE P1471 Recommended Practice for Architectural Description. The P1471 meta-model is shown in Figure B-1 as applied to the LSA. The model allows many architectural descriptions based upon stakeholder concerns. These concerns are satisfied by models which reflect a view based on viewpoint which covers the stakeholder concerns. Some of the common viewpoints are enterprise, information, computational, engineering, testing, and technology. The views in this appendix are mostly engineering views providing the structure of the LSA with

some indication of where process models would be included. The top OPD in the LSA places the evolution of the LSA as a process with relationships to the systems environment, the customers, and the benefits derived from having an LSA.

The process of LSA evolution interacts with technology, Space law and regulations and produces the benefits. The format of this OPD is based upon the lifecycle of a system presented by Dori [2002a] and in this case represents the LSA at two levels, one being any individual system in the LSA and the other being the LSA itself,

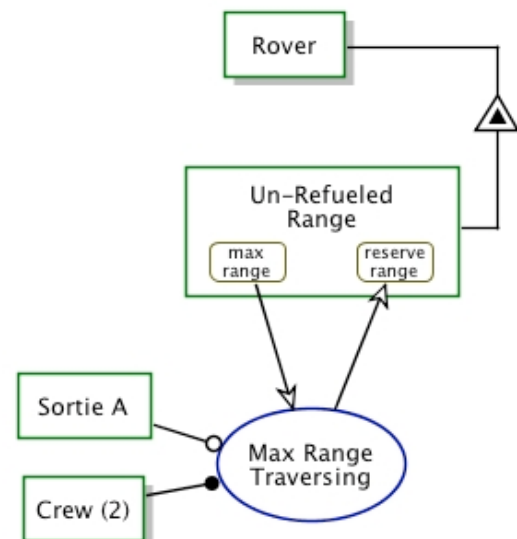


Figure A-2 Specification of maximum range functionality for a lunar rover

The LSA evolving process is decomposed into subprocesses and objects interacting with those subprocesses. At this level the LSA is presented as a discrete object which fulfills the required function set. As the required function set changes or the system evolves

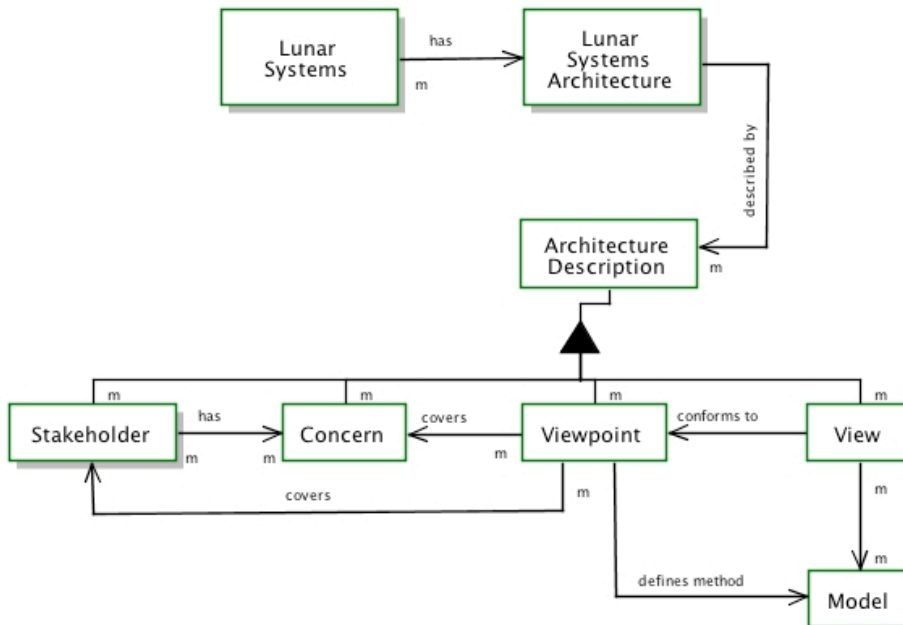


Figure B-1 LSA architectural framework Model

to be out of compliance with the requirement set, a new round of the initiating process is triggered. The deployment process tracks this as well as utilization of the system and its retirement.

The utilization of the architecture would involve a lunar mission, represented by an object that would be specialized for each individual mission, with a probable subset of the LSA participating. The conduct of the mission would exist as a process enabled by a lunar mission crew. Continued analysis of the mission would include the processes of entering lunar orbit, landing, a rendezvous with the pre-delivered rover and the conducting of traverses in the rover, followed by return to lunar orbit and to Earth. As this paper examines the modeling of human processes in conjunction with the rover, the LSA will only be further developed to show the structure of the LSA down to the rover systems.

The components of the LSA are things that are required to perform and support lunar activities, The components represent existing facilities such as the Mission Control Center and categories of resources such as satellites, scientific equipment, and human related systems such as a rover. The science side of the LSA is not well developed due to the choice of examples which aren't related to science. These components would also include assets from other nations that may be called upon to participate in lunar activities. It is important to note that each of these objects would have a set of attributes which describe them, such as size, mass properties and performance. They would also have

associated processes which would describe their operation, related tests and processing for use. These data would be organized by views based upon the top P 1471 like meta-model.

To reach the component level of the rover in the LSA, the Lunar Surface Supply Vehicle (LSSV) must be decomposed. The rover is part of the LSSV's payload. The breakdown of the rover Boeing [1965] is a work package view as opposed to a functional view. The functional models would be allocated to the rover systems/subsystems.

The scope of the information that could be contained in a LSA is large and would have to be tempered by the purpose of the LSA. An architecture such as the LSA serves several purposes:

- Systematic organization of asset information for utilization among partners.
- Long term planning for the evolution of exploration capabilities.
- System information to support system evolution and the interoperability of new system

These purposes dictate different levels of system detail, and to some extent the type of data, requiring a comprehensive analysis and prototyping of the use of an LSA.

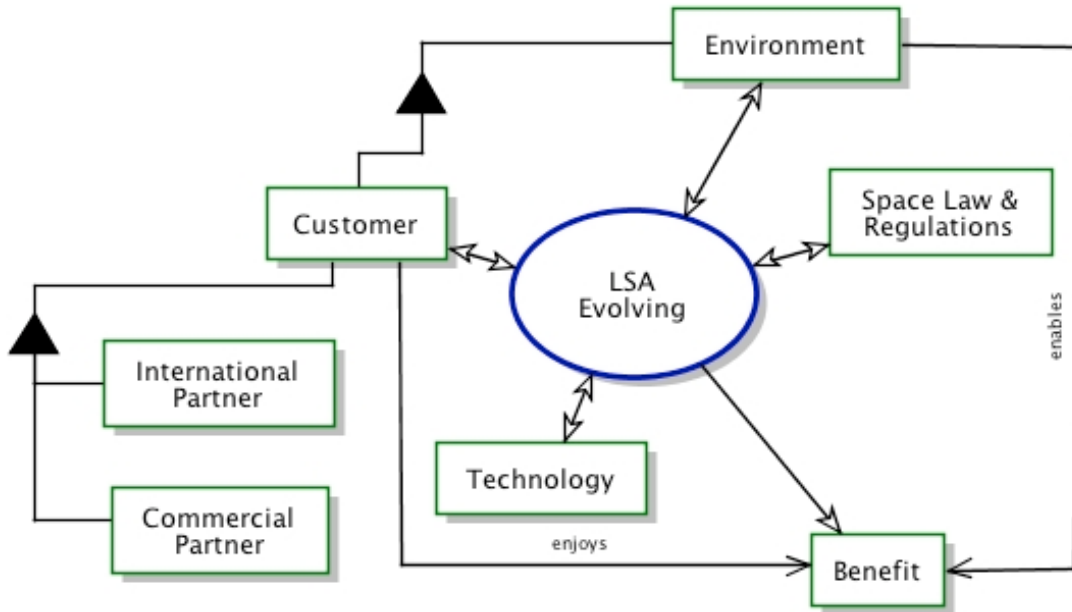


Figure B-2 The evolution of an LSA.

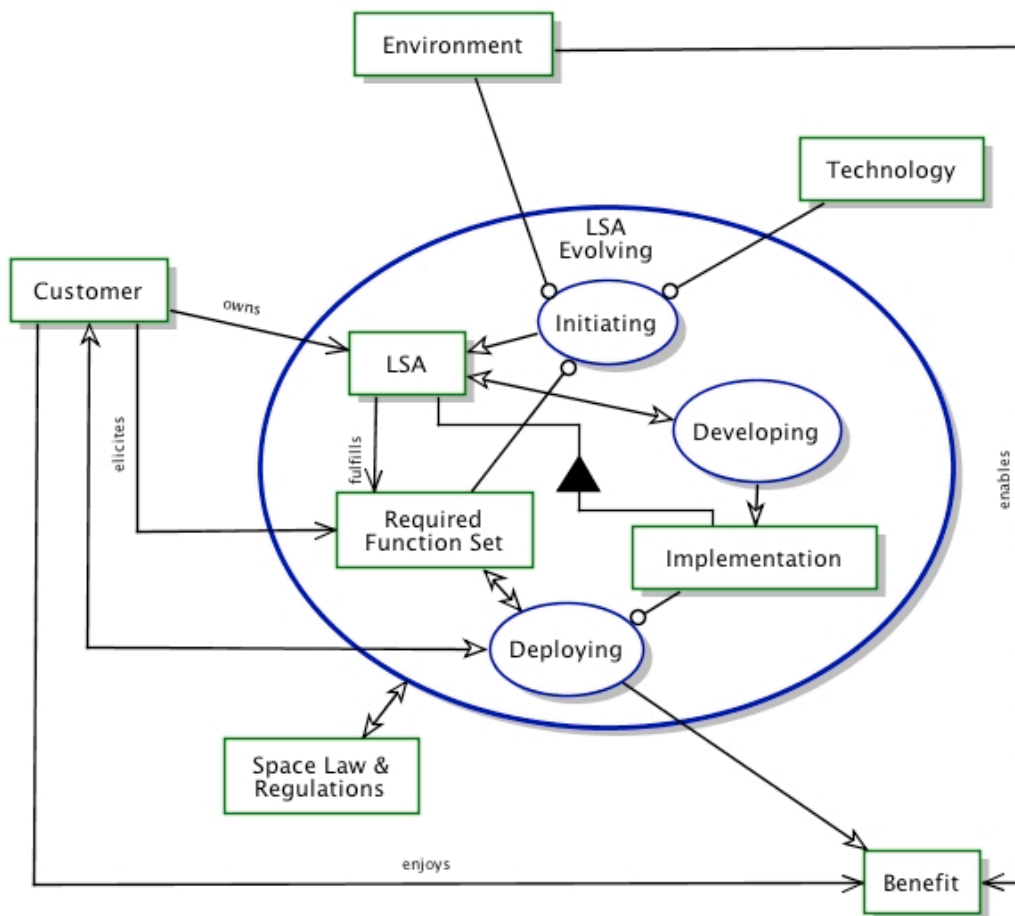


Figure B-3 LSA lifecycle within the LSA evolving Process

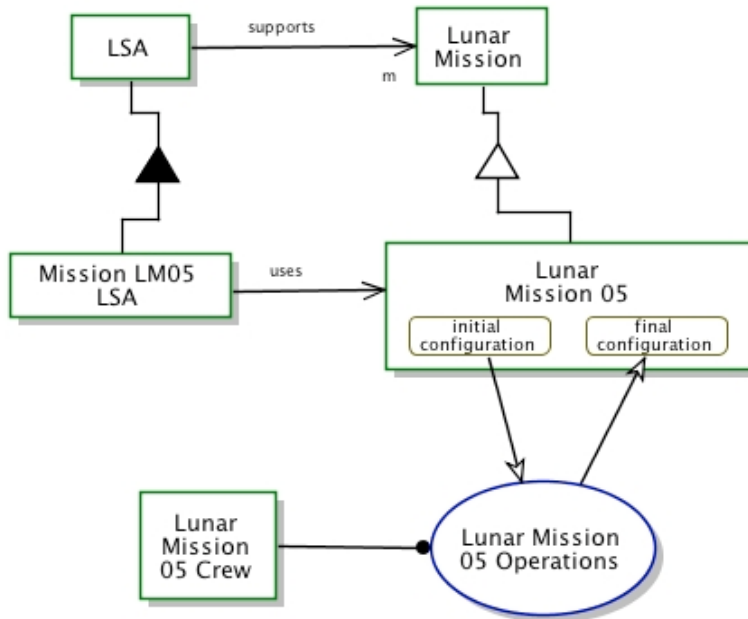


Figure B4 LSA relationship to lunar missions.

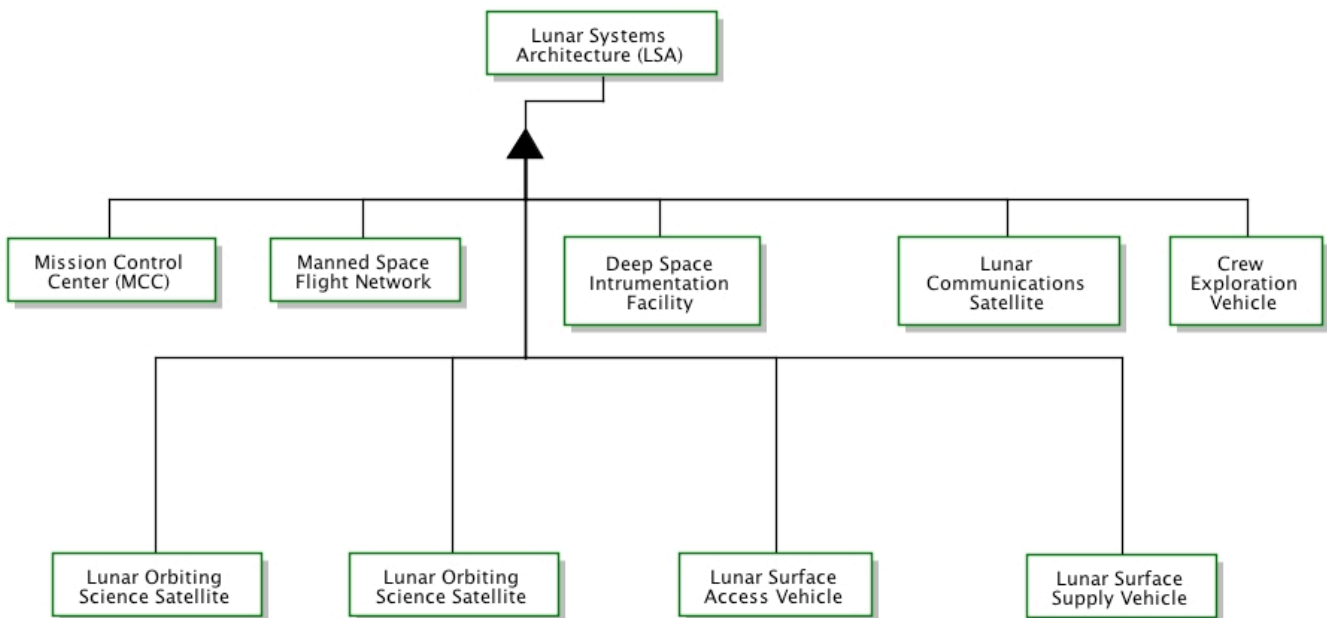


Figure B-5 LSA Component Structure.

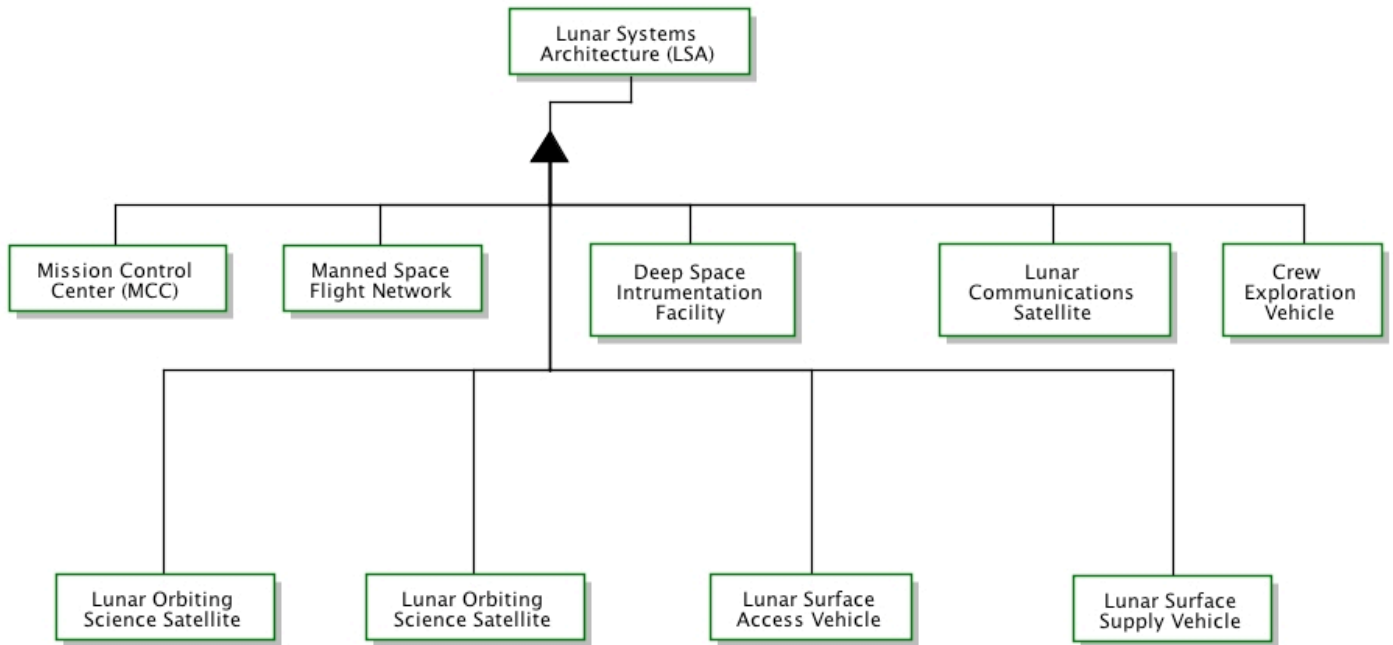


Figure B-6 Lunar surface supply vehicle component structure.

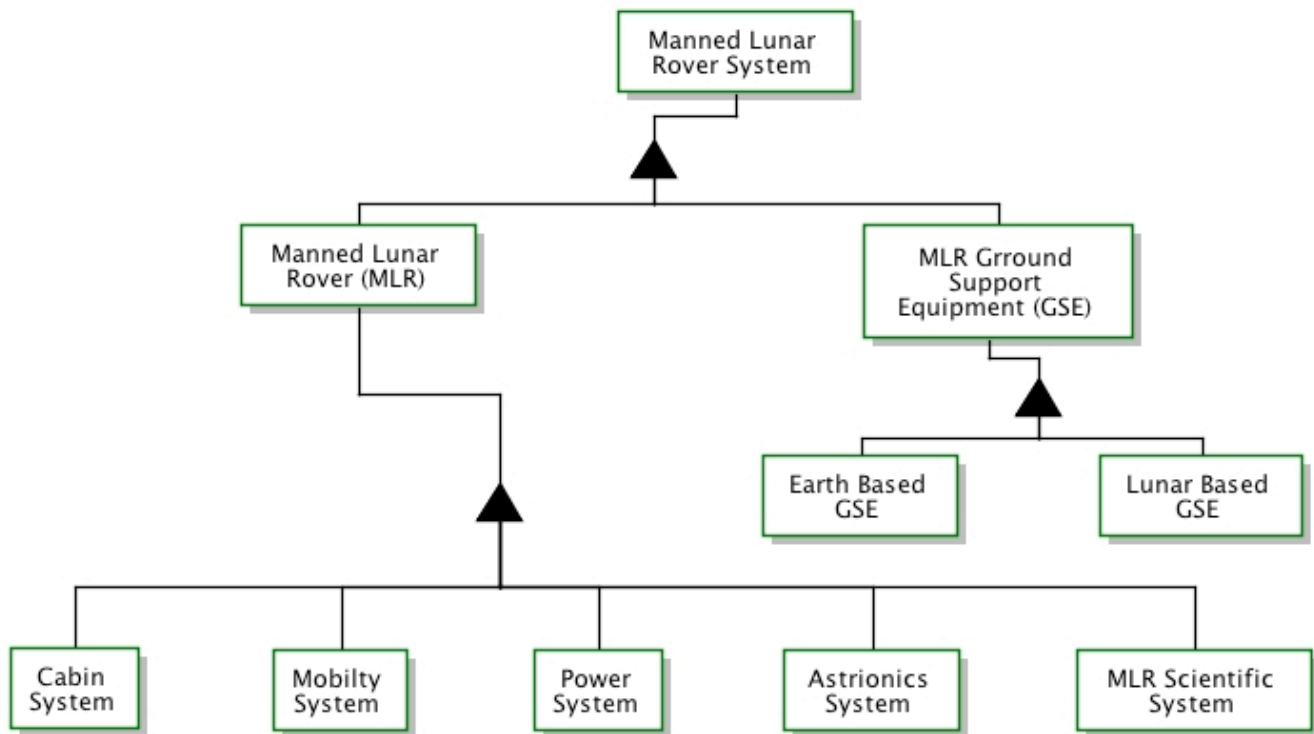


Figure B-7 MOLAB work breakdown structure.