Critical Requirements to Enable the Strategic Evolution of Space Exploration Through Logistics Development

by
Leandre Jones

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Chair of Committee: Olga Bannova

Committee Member: Larry Bell

Committee Member: Larry Toups

Committee Member: Kriss Kennedy

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For peace, love, friendship and happiness.

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Thanks to all the professors at SICSA.

ABSTRACT

Successful future space exploration requires a forward thinking process that considers the evolving functions and logistics as the exploration effort increases. This thesis suggests there is not enough weighting on the logistics effort for space exploration design. The solution is an adaptable logistics facility containing common critical infrastructure, but adapts alongside changing functions along with facilitating the evolutionary process of the function of each location. This general outlook on space exploration development aims to increase the effectiveness and efficiency of future mission architectures for the Moon, L2, Mars and beyond.

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1 Vision Mission Goals Objectives

The vision of this project aims to transition space mission planning from consumable oriented missions to a scalable, logistics focused methodology for traversing the solar system no matter how technology develops.

To accomplish this vision, this thesis poses the following problem. Successful future space exploration requires a forward thinking process that considers evolving functions and logistics for developing unknown territory. This thesis poses a mission architecture for a station that evolves with the functions of each destination as humans extend their reach throughout space.

1.1 Goals and Objectives

The first goal is to conduct research and identify key areas that drive logistics functions across different expansive large scale operations. The second goal follows by identifying the overlapping or important processes to apply to the logistics station architecture.

1. Identify the logistics operations from operations such as research bases and military campaigns. These operations provide insight into how to develop the logistics to support the mission as goals, destinations and available support changes.
2. Identify Mars vital equipment and logistic functions from the Design Reference Mission 5 to understand the baseline equipment necessary for a Mars mission. This gives insight into how to develop the Mars mission from the starting equipment. Lastly, it reveals overlapping infrastructure required for each destination.
3. Detail the important logistics functions derived from research and the logic behind developing their analogous applications for space exploration.

Goal three requires a walk through of the overall plans and processes for the forward logistics station based on the operations derived from research.

1. Develop a concept of operations for the growth of a forward logistic station on Mars, highlighting how the logistic lessons are applied

2. Derive additional important functions from the gaps in the ConOps that relate to the logistical setup, everyday operations and interfacing with other vehicles.

The fourth goal is to justify the need for refueling and fuel processing operations in L2 for the forward logistics station

1. Develop a spreadsheet to compare the fuel cost relationships at different destinations to reveal the importance of no gravity well at L2 and when the ISRU investment at the Moon pays off.

2. Expand on the functions operations accompanied with an orbiting fuel station

The fifth goal requires an understanding of the current, near and possible long term future functions of each destination (LEO, L2, Moon, Mars and Beyond). The final goal is to develop the architecture for the forward station to follow and support the destination function transitions.

1. Combine the forward logistics's station birth operations with NASA's LEO plans

2. Describe the Moon's functions overtime and explain how forward logistic station assists in the development between the functions and the functions during each state.

3. Leverage the benefits explained in L2 by involving L2 into the forward station development plan

4. Showcase how the expansion logic remains consistent for the expansion to Mars

5. Convey how the plan operates for the unknown expansion opportunities beyond Mars.

2 Background Logistics Research and Its Impact

The functions of this research are to understand the expansion choices for large scale exploration, science and military endeavors related to logistics. The rationale for their logistic choices and implementation methods must be understood in order to derive analogous solutions for space. This section will discuss parallels between the logistics choices and how they can be expanded for space architecture. Adaptations of these logistic ideas were identified in space endeavors like COTS and the ISS for deriving additional logistic parallels to draw upon. These offer proven examples of how core logistic ideas were adapted for space exploration.

To facilitate analysis, several questions were proposed. These questions were derived with the intent to extract whether the scenario has applications according to the evaluation criteria. Also, the questions reveal understanding for how the scenario's expansion processes affected their logistic drivers.

The following are the questions:

1. What are the goals of the operation supported by the logistics?
2. How do the mission goals influence or determine the logistic design drivers?
3. How do their logistics evolve over the expansion or lifetime of the operation?
4. What are critical ideas and processes for establishing and supporting the logistics supply train?
5. What are the critical infrastructures for establishing and sustaining the logistic supply train?
6. What are the critical, common or apparent risks to the logistic train and what is the contingency plan or mitigation plan?

After the key logistic processes are identified and underlying logic for them is clear, its set aside to compare at the end of research to identify parallels.

2.1 Antarctic and Arctic Research Bases

2.1.1 Point Barrow

One of the most overlooked aspects of the Point Barrow Arctic Research lab was their effort to attract research partnerships during its development. Mutually beneficial agreements like these are the backbone of a capitalistic economy and will always lead to rapid, major growth in almost any sector. For the station it opened the door to exploring the political and money drivers for defining a logistics development train. It reveals the idea of adhering to the needs and wants for the highest influential player in the scenario. Once their base needs are satisfied, the logistics train can use that momentum to support the transition to future branching endeavors. Secondly, the entire base was built from the remnants of a Naval base constructed years ago from Seabees. This is the idea of re-purposing past infrastructure. Again, leveraging the gains from seemingly unrelated endeavors for double or even triple dipping the benefit. This reveals the advantages to re-purposing a facility to extend the value of the initial labor to implement it. The facility was built for an entirely different purpose initially, but it was re purposed with some additional infrastructure to facilitate the new functions. All of the old functions were either kept on to support the mission, transitioned for the new needs or gutted. However, this is only successful if the effort required to re purpose or use the old functions exceeds the investment for an entirely new vessel.

2.1.2 Race to Antarctica

The main lesson learned from the Antarctica races was the importance of establishing a logistics path from home base to a far out location residing in an extreme and hazardous location. The logistics pathways is necessary for all large scale efforts such as these. It should be clear how each step moves from the next and the infrastructure needed to facilitate the actual transfer.

Next, its imperative to incorporate long term logistics into a level one design requirement for the mission architecture. Having requirements at the first level for interfacing with long term logistics is a vital step for a step-by-step approach to exploring the unknown. Designing for logistics now makes it easier down the road to expand on the mission and go even further. You don't need to spend effort, money and time redesigning a thing if care was taken in the beginning to account for transforming functions and planned obstacles.

A more subtle logistics trick is caching supplies along the exploration or development route. Caching essentially means dropping consumable supplies or leaving operational vehicles, mining rigs or even habitats for people to rendezvous with and extend the duration of their trip. By using a method of transportation to deliver supplies that can bypass human limitations through speed or autonomy, the mission can be expanded by having cache checkpoints to resupply the humans.

Transitioning the crew supply network from consumable supply sources from home base to resources harvested at the destination is the goal for any logistics endeavor. The supply train functions to facilitate this transition, but the end goal is always total independence so that the forward node operates as the next home base for the next node, and so on. The sooner the mission derives consumables from the destination, the sooner the base becomes independent of the home and the logistics scaling can propagate again.

One of the most interesting points from this research is the "Dogs eat Dogs" philosophy. The presenter discusses how the explorers would feed their dog sled team to each other as the cargo load lightened. They needed less dogs to pull the sled, and also didn't need to pack dog food because the unneeded pulling power fed directly to itself. The other team utilized horses, which required allotted cargo space for hay in addition to feeding the full sled team along the way. The dog sled team arrived faster and in better health. Generally, this is referring to the concept of finding creative methods to obtain multiple uses out of the supplies and infrastructure used to get to the destination. Pulling more than one use of of a supply benefits the expedition exponentially more than packing an object for an individual use. This is because it means less things need to be brought and there is more room for more supplies which means the trip can go further and last longer.

The presenter trip explicitly coins the logistics development method the step-by-step approach for exploring and conquering space. This refers to establishing footholds closer to the destination, allowing a freshly supplied mission to start closer to the destination. Again, means they can go further and longer.

A more subtle logistics requirement involves dealing with waste in a far destination. Resupplying along the trip is already a task, but ensuring no waste is left on the exploration site or route that could contaminate the environment is equally as important. Ignoring the ethical arguments for contamination, there is a clear case against it from a logistics point of view. Building waste in a far location without the infrastructure to handle will hinder the ability to work and expand. The logistics scenario should find a way to reduce the waste or re-purpose the waste for multiple uses. To scope the problem, present day Antarctica bases ship their garbage by freight ship to the United States. Dealing with waste on the Moon and Mars should be better than sending launch vehicles back to LEO filled with trash.

Lastly, a nuanced lesson from this research is the importance of establishing and maintaining a communication and navigation infrastructure. Navigation and communication systems at the destination drastically improves the quality of life and ease of traveling. This is a key utility for a stepping stone logistics strain system.

2.1.3 Military Campaign Logistics Research

Military campaigns are often won through the careful planning and execution of the resupply logistics. The importance of logistics to the success of an operation make its imperative to incorporate logistics design into the mission architecture. The success of any military operation is divided between tactics, manpower and logistics support. Without logistical support, an the entire operation will fail, but wars have been won with imbalanced force sizes.

A basic logistics idea employed in the military is sending large equipment through a faster, less human friendly travelling method while the humans follow through a different route. This is an important logistics strategy to employ depending on the circumstances of the mission. With the advancements in automation, it will be possible to deploy large scale infrastructure without human aid. This facilitates the use of sending cargo separately from humans.

Another core logistics strategy is the usage of multi-functional forward logistics node, or magazines and the Loss of Strength Gradient. The magazines were basically fortified resupply stations that were built as the front line advanced into enemy territory. They are useful on the offense to keep the front lines refreshed and doubled as a defensive position to hold off enemy advances until reinforcements came. The Loss of Strength Gradient refers to how a military's power drops rapidly the further away from home base their front line advances. Forward nodes offset this through providing supplies and extra mobility far away from the home base.

Another key to a successful logistics operation is the development of infrastructure to support the logistics train. The logistics train effectiveness increases drastically when infrastructure supports it roads, fortifications, sentries. Its important to note that the nuances of fortifying a logistics train has different meaning for military versus a resupply run. The firepower required to defend the train makes this more important for military operations.

Russian's standardization of resupply has always made them a formidable opponent in wars throughout history. The first seems to be common sense, but the complexities of most operations makes this lesson lost. Its extremely important to design and sort the resupplies in a standard format depending on the type of supply. Making everything standard makes the process less likely to fail and easier to repeat. Again, this seems very simple, but unfortunately, as the design and mission scope become more complex, its very easy to trade the standardization convince to make some design component easier. How this plays out is extremely case by case, but the overall idea is to avoid trading short term convenience at the expense of long term convenience. Additionally, the Russians excelled in a staged resupply system. Holding supplies in stages behind the actual front allows a tactical distributing of the supplies depending on the specific needs of each destination. Avoids wasteful stockpiling of supplies in distressed areas while supporting the fronts with a high chance of winning. Essentially, maximizing the output of the military while minimizing the wasted resources on failed pushes.

Lastly, its important for the organization supporting the resupply to collect data on depletion rates and the variables that affect them. Think of this as building a machine learning algorithm that will make every resupply easier, and more effective down the line. In addition, its important to incorporate infrastructure and organization to track the depletion rates. This is another critical element that can be overlooked. Adding it after the operation train is running will be very cumbersome and expensive. So, taking the time at the begging of the mission architecture to plan it is important. Find patterns of how supply depletion rate may increase or decrease depending on the mission operation.

2.1.4 ISS Logistics Research

This research focused on some of the important nuances related to logistics from the ISS design and operations. These are key ideas that any logistics train operation should incorporate into the design. Firstly, unpressurized exterior cargo storage is an amazing time saver. By expanding storage locations to the outside of the vehicle, it allows easy access to unpressurized cargo. This completely cuts of the time to cycle airlocks which speeds up cargo transfer. Also, by standardizing interfaces for payloads, vehicles and cargo storage, it drastically simplifies the all logistics procedures and allows mission operations reduce their duration through learning.

The ISS growth pattern followed a step-by-step approach. Using standardized interfaces and shapes, the ISS was able to grow through modules. The ISS showcases a successful model for improving the infrastructure of a station over time. Its important to have infrastructure before the transition to facilitate the actual transition process. For the ISS, this includes the Canadarm track which expanding the mating processes to include berthing.

The ISS and ground teams took meticulous notes on the supply depletion and maintenance rates. This informs the logistics of what variables affect resupply rates. Additionally, it reveals which systems on the ISS require substantial maintenance to warrant a redesign. Dividing and tracking the supplies allow people to rack the consumption rates to give better idea of to effectively resupply. Also, it shows the levels of margins to prepare for a human mission. After understating the maintenance rates, logistic improvements like 3D printing or manufacturing the maintenance pieces on the station will make all future resupplies simpler. Lastly, the frequency of resupplies will affect how the storage is packed and how future logistic nodes are distributed out and designed.

The last big design lesson is actually an oversight in the storage on the ISS. A big problem the ISS faces is how the storage is conducted. Mismanagement of storage often results in delayed resupplies or even crucial crew time spent locating some. Proper layout and organization of supplies will assist automated and crew to search and transfer. The ISS is planning to accomplish this through a tagging or Radio Frequency Identification (RFID) system. This is a mediocre option to band-aid this problem because the effort to tag all old cargo is cumbersome. Incorporating a solution like this early on in the mission architecture would see monumental time savings.

3 Understanding Entry, Descent and Landing (EDL) and Descent, Ascent Vehicles (DAV) Methods

The next research section focuses on the lessons derived from EDL and DAV vehicles as it relates to the operation and design of the lander taxi.

3.1 Curiosity Rover

The Curiosity Rover Skycrane delivery method provides a proven architecture to deliver small payloads across the surface with relative precision. This provides a method to utilizing the caching logistics strategy in a space format. Imagine a network of Skycrane delivery drones that scatter small payloads across the surface for the crew to rendezvous with later. Instead of crash landing on the surface, they can return to the home base for more cargo and attaching themselves to the lander for redeployment once the lander descends to the surface again.

3.2 Mars DAV

The Altair Descent Ascent Vehicle (DAV) uses two main hatches on the vehicle. The main hatch allows delivery of cargo and people on the surface. Its designed in a way to that crew and robotics designed for surface use can effectively interact with it. The top hatch allows delivery of cargo and crew while in orbit. Similar to before, the space hatch is designed with the idea of a crew, robotics and cargo are interacting in a micro-gravity situation. Utilizing the surface area of the lander to place multiple doors facilitates cargo transfer in orbit and on the surface better than if just 1 door existed. This allows each door to be designed specifically for their own functions to increase the effectiveness of the cargo transfer.

The largest attention grabber, of the Altair is the duel use of the launch vehicle upper stage with the lander descent engine. The dual use of this architecture provides amazing mass savings down the road. This is a direct application of the dog eat dog mentality for an in space environment. Find multiple uses for infrastructure is a massive boost for the effectiveness of the logistics train. Especially something as massive and complex as the propulsion system because of how hard it is to replace after its deployed in space. Adding the synergy for removing waste thrown into space makes this an interesting endeavor to pursue for a logistics tran.

Habitank

The Habitank was a dual purpose design study to understand the trades of repurposing a fuel tank into a functional habitat. It was a useful research topic because of the detail about the tasks a crew performs to outfit the habitat into a safe place to live after being used to fuel a launch vehicle. The repurposing of equipment that would have been tossed is another great example of the double dipping logic of "Dog eat Dog". Again, increases the effectiveness of the logistics train to gain long term value out of a piece of infrastructure that would be refuse. This research revealed how to frame the design process for reuporosing a piece of equipment as a trade off between designing for the three main attributes. These are the functions of the first phase, functions to facilitate the transfer, and the functions of the second phase. Generally the effectiveness of the reuporsed design before and after the transition changes with how you weight each stage in the design process. For example, for the Habitank, the tank design suffers if the design focuses on habitat portion and vice versa. The gains from a repurposed design plus the drawbacks in effectiveness should be compared against a traditional design. Its important to weight all the future gains correctly to account for all the long term gains and convenience versus the initial, short term fall backs.

3.2.1 Lunar Taxi

Research from Lunar Taxis revealed some key functions a logistics station would need to have to be effective:

1. A Staging Location for Vehicles at the Moon,
2. Facilitate Crew Transfer while in Orbit
3. Communications Platform
4. Reusable Lunar Lander that Remains on the Surface
5. Exploration Capabilities for the Entire Moon Surface

6. Refueling Depot for the Lander and Future Vehicles

7. Emergency Safe-haven and Lifeboat Capabilities for Crew

These were used as cornerstones for deriving the ConOps of the forward logistics station.

3.3 Space Shuttle

The Space Shuttle offers a lesson on the catastrophic effects of not incorporating logistics into account at the beginning of design. The space shuttle requires 750,000 man hours between each space shuttle launch. The total amount of launches from the space shuttle were severely reduced. One of the big reasons for this bad turn around is attributed to the heat shield. Each piece of shield is unique and must be meticulous replaced. Standardizing the pieces more would drastically improve the turn around time of the Space Shuttle resulting in more flights. To compare, the Falcon 9 is aiming for 10 launches without refurbishment and a 24 hour turn around period. While comparing the shuttle to a launch vehicle isn't a fair 1:1 comparison, its still an interesting case study on how much more effective a project is if reusability and repurposability and incorporated into level one design requirements. Its harder to extract analysis from the specific ways they the falcon 9 achieved quick turn around times, because the design choices are done in parts that are more nuanced and beyond the scope of this paper.

3.4 Cryogenic Fuel

Scheduling take offs, arrivals and the ISRU production system. Water sits in a state that will not boil off until electrolysis is required to prepare for an approaching vehicle. Cryogenic boil off rate is the largest roadblock preventing this high ISP fuel from performing. The nuance of designing a cryogenic shielding storage mechanism is beyond the scope of the behavior; however, the boil off problem can be combated from a logistics planning perspective. By storing the mined water as ice or water, and starting the fuel creation process as soon as the time between the arrival of the launch vehicle equals the time it takes to produce a full tank of fuel. This is an example of a logistics design that will scale well with technology advancements. The time will just shrink as cryogenic shielding technology increases or propulsive methods are faster. It will have trouble scaling for multiple vehicles as the fuel tanks needed to fill eclipses the ISRU production rates. But, this shows when additional ISRU units are needed.

3.5 Background Research Analysis

Useful information pulled from the DRA5 like timelines and important equipment that should be transferred to Mars. That leads to more functions for the logistics node to support.

Research Design Reference Mission 5 to understand the current Mars exploration philosophy and vital equipment for Mars travel as proposed by NASA

(Understand what kinds of equipment will be set up to back out how to deliver and support it. (understand the reasons for why equipment is place to grasp where else it will be needed and when its no longer needed, or if it can be replaced) (Understand overlapping infrastructure required for each location and their evolving functions and emphasize importance)

3.6 Key Parallels for Space Exploration

The important lessons from research was stated in their particular section; however, the main parallels consistent between most of the areas should be addressed. The most repeated point from the research was a logistics node. The number one contribution to success from logistics this node. The general uses of this node are to provide key infrastructure to support future growth and operate as a staging point or small base to assist with rendezvous and mission tasks. This generalized concept is applied in different methods depending on the context of the mission, but it's still the most consistent idea. The logical conclusion is to try this method for the Mars campaign. This thesis proposes repurposing the transit vehicles as the starting infrastructure to facilitate future growth. Those key elements are the orbiting station as the staging point, the Mars oriented DAV to assist infrastructure development on Mars and increasing the storage capabilities.

A key part of the design process for each system is identifying the functions from each phase and what overlaps. More overlap and less unique functions means a reduced design cost for the end product. The three systems identified above are the starting point for other possible systems. Further work should be done to generate an evaluation criteria to determine the value of repurposing other systems. The logistics station has overlapping functions for all of its core functions. As the cargo Mars Transit Vehicle, it contains engines, avionics, autonomous systems, solar panels, RCS, TCS and docking ports. All of these systems will be utilized in its life as a orbiting logistics station. Additional functions for changing to fuel to methane, refueling, transferring payload, storing payload and possible human factor functions. The DAV is being repurposed from the propulsion stage. This system requires more design work since the only overlapping functions are the engines, RCS and large fuel tank. Additional requirements include handles, hatches, small payload platform and way to repurpose the solar arrays. Lastly, the tanks are great value since a lot of power and resources are dumped into the TCS. Originally, they're dumped into space, but will serve a longer purpose as a surface tank. Some additional design requirements are handles, refueling interfaces and attachment points. More details on these requirements are in the matrix below.

4 Deriving Functions from ConOps

After understanding the key operations for a successful logistics operation and deriving an analogous application for space, a concept of operations is detailed. This highlights nuances and additional functions needed to fully apply the key logistics lessons. Additionally, it reveals the harder to pinpoint functions needed from the forward station to successfully operate as a forward logistics node.

4.1 Overarching Forward Station ConOps

How the logistics facility scales for further destinations (Europa ETC) and scales in size to accommodate for larger infrastructure. The projections made for future functions of each location need to address. how the demands are quantified

1. Understand functions for Earth and Moon at Time A. These are X.
2. Develop projections for functions for Earth and Moon at Time B based on research, NASA's plan, commercial space plans. These are Y
3. Understand the functions needed to transfer between the time A and B. These are Z.
4. Understand the functions no longer needed at time B for Earth and Moon. These are W.
5. Derive the requirements for a space facility (facilities) that addresses X,Y,Z and Y-W.
6. Repeat for Time C.
7. Highlight the common functions between all times. These are the key logistic functions that make up the baselines needs for a logistics facility.

The forward station timeline begins with a healthy commercial transfer vehicle economy and the ISS sitting in LEO. Private companies are regularly contracted by NASA and other government bodies to resupply the ISS, send experiments or transfer crew. Additionally, the transit economy is growing in other sectors like occasional one-way payload delivery to the Moon and Mars. The frequency of trips to the ISS, Moon and Mars warrant a forward logistics node to reduce the costs. At this point, the forward stations are sent into LEO to support research endeavors that can or need to operate outside of the ISS orbit because of individual requirements of the project or to accommodate countries without launch sites fitted for the ISS. Providing a larger, and easier to access "railroad" system to the LEO market will allow more investors and opportunities to come resulting in a snowball effect. While the economy grows, the NASA continues to test and improve the next generation exploration ECLSS, power and ISS systems. Once completed, these are sent to the Moon to begin stockpiling fuel.

Once the forward station's responsibilities grow enough, the forward station's capabilities grow to match. The forward station begins to support a global lander taxi system to deliver payloads, fuel, supplies or whatever conceivable item that the future markets require. This system continues to grow while the Moon forward stations begin their expansion.

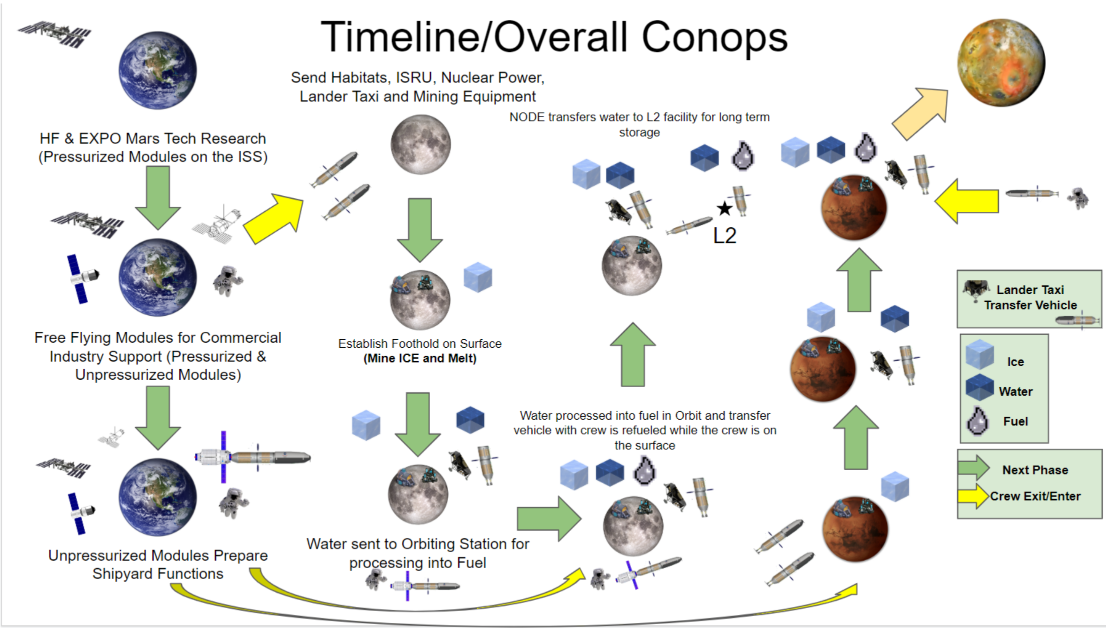

Figure 1: Concept of Operations for the Overall Growth of the Forward Logistics Station

4.2 Moon, Mars Beyond ConOps

The earth sends a couple of payloads that include a habitat, mining equipment, power system, storage and an ISRU facility. Once it reaches the Moon's orbit, a Moon oriented version of the forward station taxi system developed on Earth delivers and deploys the facilities to the surface. The nuclear power system is deployed first to initiate the power creation required to deploy the other facilities. Once the mining equipment is setup, the ISRU facility is powered on and the fuel creation process begins. The mining facility continues to create raw resources until another craft approaches the Moon's orbit. To minimize boil off from stored cryogenic fuel, the timing is set so the lander reaches the orbiting forward station as soon as the approaching vehicle arrives. The lander is filled without enough fuel for a trip up and back.It brings enough raw fuel resources to top off the forward station and the new arriving vehicle. The raw resources are not converted into fuel until the time it takes to create the fuel equals the time remaining until the vehicle is ready to leave. Again, this is to minimize boil off. The raw fuel resources are transferred to the forward station for processing while the crew and cargo going to the surface board the lander. The lander deploys any necessary cargo and the crew conduct their mission. In the meantime, the ISRU loads more raw fuel resources and a full tank of processed fuel for the lander. The crew and cargo board the lander and ascend to orbit. The fuel processed in the orbiting forward station is transferred to the transfer vehicle and the crew departs back to Earth. The station accepts the raw resources from the lander and awaits the next vehicle. This process repeats and is simple enough to be scaled more with additional fuel, storage and forward station facilities. Once the frequency of missions reaches the limit to warrant additional infrastructure investment at L2, a dedicated fuel processing depot is sent to sit at L2. Raw resources are sent to L2 to accommodate the refueling needs of a constant traffic through L2. This is enough infrastructure to accommodate the LEO economy to expand to the Moon. Then, the possibilities for new markets and players in the space economy allows for unprecedented accelerated growth. Additional habitat, ISRU, mining and power facilities are sent to Mars and the process can be repeated for the next destination and on wards.

4.3 Mars ConOps

The Mars ConOps is identical to the Moon, but one variant is provided to show the growth options of the forward station on Mars. Additionally, more detail on the transfer to Mars is shown with a simple ConOps graphic.

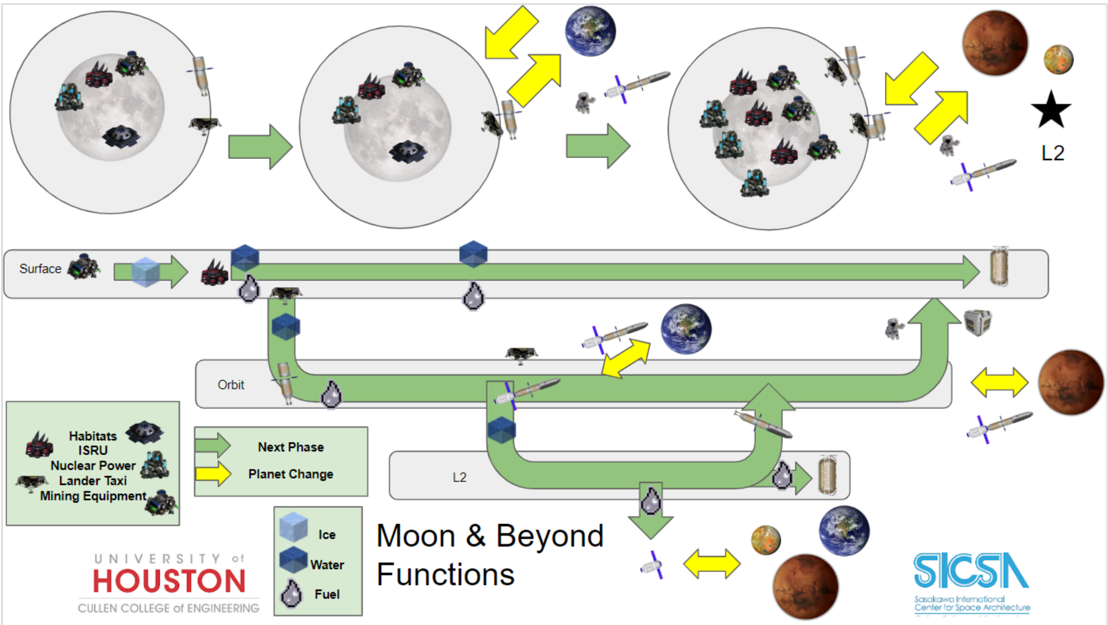

Figure 2: Concept of Operations for the Growth of the Forward Logistics Station on the Moon

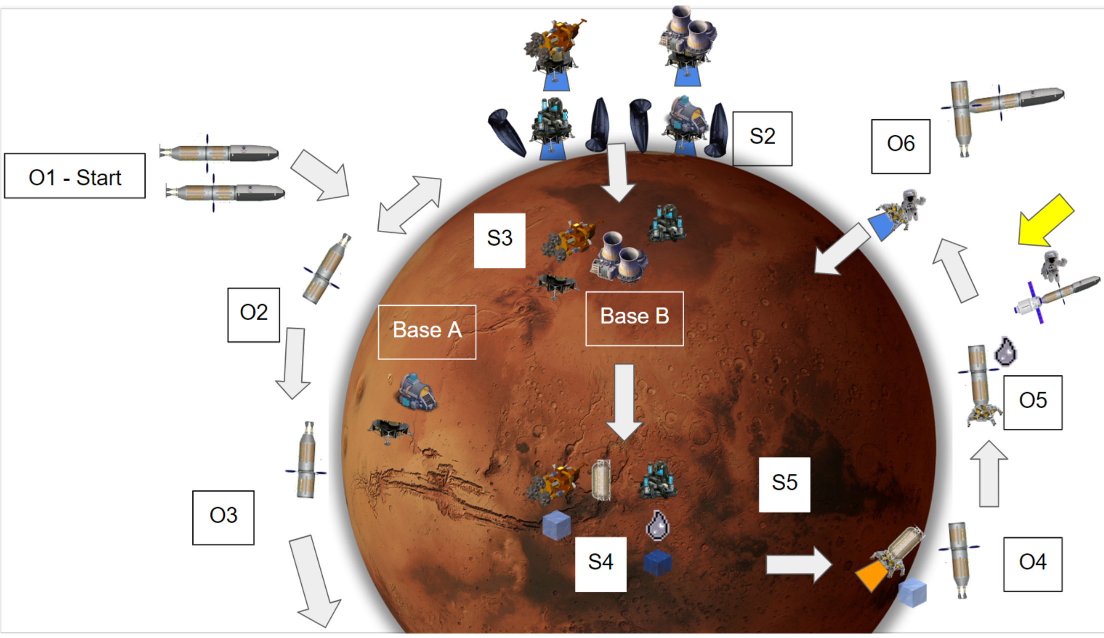

Figure 3: Concept of Operations for the Growth of the Forward Logistics Station on Mars

5 Forward Station as a Propellant Depot

What started as a location evaluation criteria developed into understanding the values of each destination in terms of the fuel delivered as a payload versus the fuel burned. One of the largest contributions from the logistics station is the ability to extend the reach of spacecraft originating from Earth. By understanding how each destination can multiply the distance traveled from each ship, the key locations across the forward station's development are identified.

The fuel burned to travel to other destinations will factor into how valuable it is to store infrastructure there. Since the station serves as a gateway that houses replenishing infrastructure to reach further points of interest, strategically placing the station is critical to the value humanity can derive for exploration. For this analysis, the resources available on the planet from ISRU are assumed to be infinite. This analysis discusses how much fuel would be required, but does not comment on the capabilities of projected ISRU technology. The logic of the station's development is consistent and scalable not matter the fuel production rates.

5.1 ISRU Investment Payoff Point

The Transfer Efficiency Ratio (TER) is corrsponds to the ratio of payload delivered to the propellant burned. A value greater than zero means the payload of propellant delivery mass is greater than the mass of propellant burned. Less than zero means the craft burned more propellant in the transfer than the amount delivered. The crossover point refers to how the TER changes over different trajectories. For example, bringing fuel from Earth versus the Moon for use in L2 has different implications. The investment propellant used to move the ISRU equipment to the Moon plus the reduced transfer cost is compared to the transfer cost of bringing the fuel from Earth. After a certain amount of trips, the investment pays off.

Firstly, the delta-v between every destination was calculated including the delta-v to move from the surface to orbit on each planetary body. Then, different combinations of stops are simulated to obtain a value called the Transfer Efficiency Ratio. This value is obtained by dividing the mass of the propellant burned over the entire trip by the payload delivered. There are 3 different starting locations to that the propellant was derived from. These include the Earth, Moon and Mars and will later include the moons of Mars. This analysis can be later applied to further destinations like Jupiter's moons as the analysis matures. Next, is the 1st storage location to check the loss for storing resources at a separate location from the origin. Then, the next location is where the raw propellant resources can be electrolysised into propellant. Lastly, there is a 4th location for storing the ready to burn propellant in a separate location. This was done to solve for every possible trajectory to compare a suite of trajectories for further evaluation based on other criteria. For example, the trajectory with the highest TER might not be the ideal candidate due to lack of resources or impassible barrier phenomena. Additionally, future users may select need to weight different trajectories based on additional criteria that reveal themselves in the future like the development of an actual node, major infrastructure available in space or unforeseen technology leaps.

The algorithm for calculation the TRE comes from commonly used rocket equations. First, start with a payload size as,

$$Mpl. \tag{1}$$

Remember that its entirely propellant for the purposes of this analysis. Then, Obtain the mass ration with a chosen escape velocity (Ve). The escape velocity comes from the ISP of the chosen launch or transfer vehicle as seen as,

$$r = e^{-\Delta V/V_e}. \tag{2}$$

Equation 2 is known as the mass ratio. The payload fraction is found by subtracting the inert mass, or the mass not associated with the payload or propellant from the mass ration. This is expressed as

$$\lambda = r - d. \tag{3}$$

The data is plotted over different values of inert mass to showcase the trends of propellant delivered from less efficient vehicles. The mass of the propellant is calculated as,

$$M_p = M_o(1 - r). \tag{4}$$

The second value of the TER is the propellant mass which is found as see in Equation 4. The final TER ratio is expressed as,

$$\frac{M_p}{M_{pl}}. \tag{5}$$

The results from the Earth destinations are in the figure below. These results are helpful to identify if the algorithm is working correctly by comparing the curves. The highest line should be the curve that describes the TER for taking resources from Earth, moving it to LEO for all electrolysis and storage operations. The next highest curve shows how little the TER drops when moving the resources to L2 for processing then back to LEO for refueling. This was interesting because it foreshadows how efficient L2 is for transfer movements. This is reinforced by the next two curves that show the propellant costs for going to the Moon. The L2 route is barely less efficient. One thing to keep in mind is the route to L2 is probably considerably slower than a direct trip to L2. This analysis does not account for the transfer time so its not as useful for a trip with human passengers. This is exemplified in the final two curves. The TER ratio for going to Mars is almost twice as efficient than going to Mars. However, the transfer time difference for these trips would only make this trip viable for non human transfers.

The second set of curves apply the same algorithm for a node that extracts raw propellant resources from the Moon. The same efficiencies from L2 are exhibited in this analysis. In fact, the TER from going through L2 to LEO or back to the Moon's orbit is cheaper than ascending to low lunar orbit and descending back down. Another important note is that the TER from the moon peaks at about 10 times higher than an Earth based system. Both of these graphs begin to illuminate the savings gained from

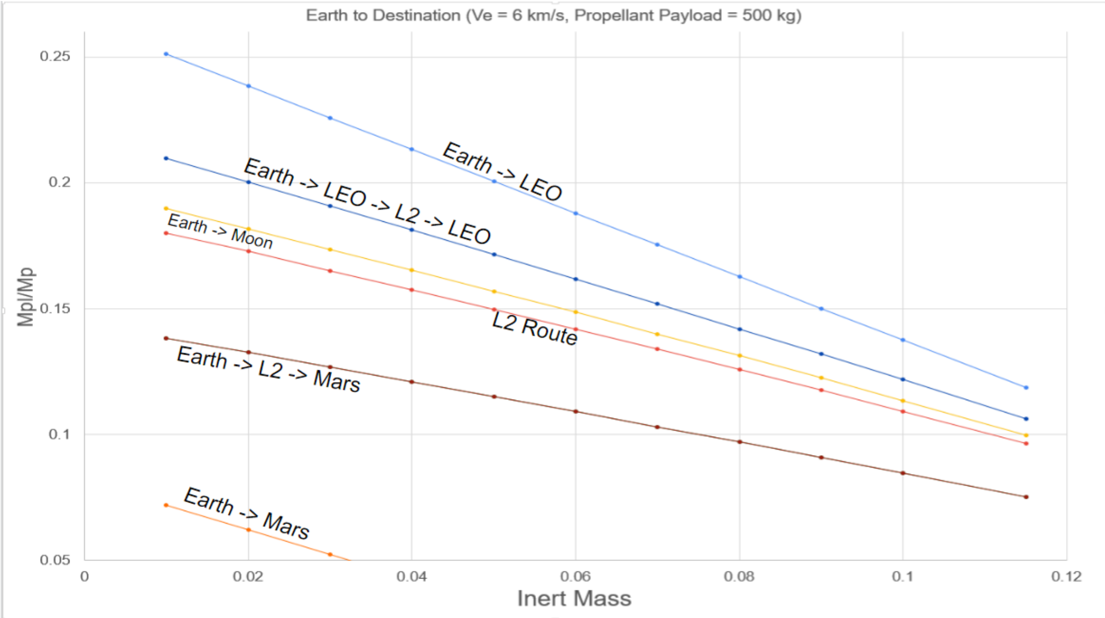

Figure 4: TER Graph Comparing the costs from Earth to Various Destinations

a forward logistics node. However, the next step is adding the losses from moving the ISRU infrastructure to distant planets.

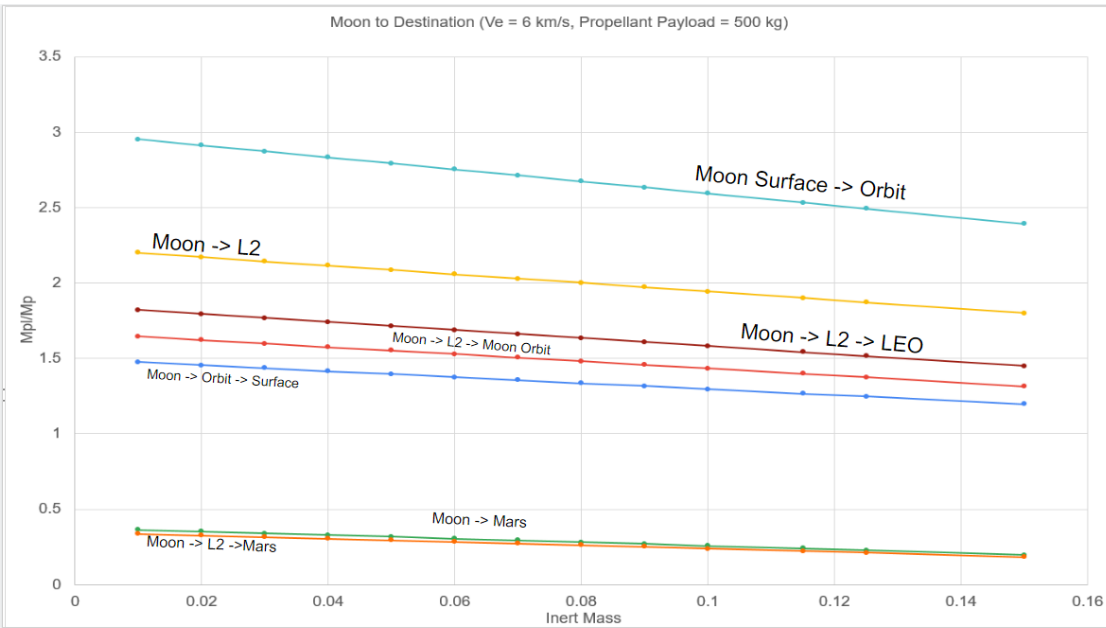

Figure 5: TER Graph Comparing the costs from the Moon to Various Destinations

The graphs above also hint to a monumental advantage of no gravity well at L2. The Mpl/Mp ratio drops by .2 while the distance moved increases by more than 10 fold. The ability to move large payloads from L2 makes it an important stepping stone to reach

Table 1: Masses of propellant production infrastructure

Equipment Name	Estimated Mass (MT)
Power System	1.5
ISRU Unit	1.5
Mining Unit	1.59

Table 2: Transfer costs between each location with an inert mass of d=.08

Transfer (Per Trip)	Propellant Cost (MT)
Equipment	4014.8
Moon-L2	.571
Moon-LLO	.374
Earth-Moon	405.54

further destinations. To put it in scale, its substantially easier to move a payload from L2 to Mars than moving a payload from Earth to GEO. Once the initial investment is made to establish infrastructure, the payoffs make future travel much easier.

5.2 Criteria 2: Crossover Point Moon

This criteria was explored for two different scenarios. Scenario 1 involves a mission where the goal is continuous Moon exploration. The second scenario describes a mission to conduct continuous Mars exploration. For the Moon scenario, three different options are compared. These include:

1. The ISRU, power and mining infrastructure are sent to the Moon. A forward station exists on the Moon.
2. The ISRU, power and mining infrastructure are sent to the Moon. A forward station exists on L2.
3. The payload is delivered from Earth each time with no forward stations.

The above graph was used for an inert mass of d = .08. After about 10 trips, the investment in ISRU infrastructure is offset. The second graph showcases the percent difference in propellant fuel burned between the L2 and Moon orbiting node. The

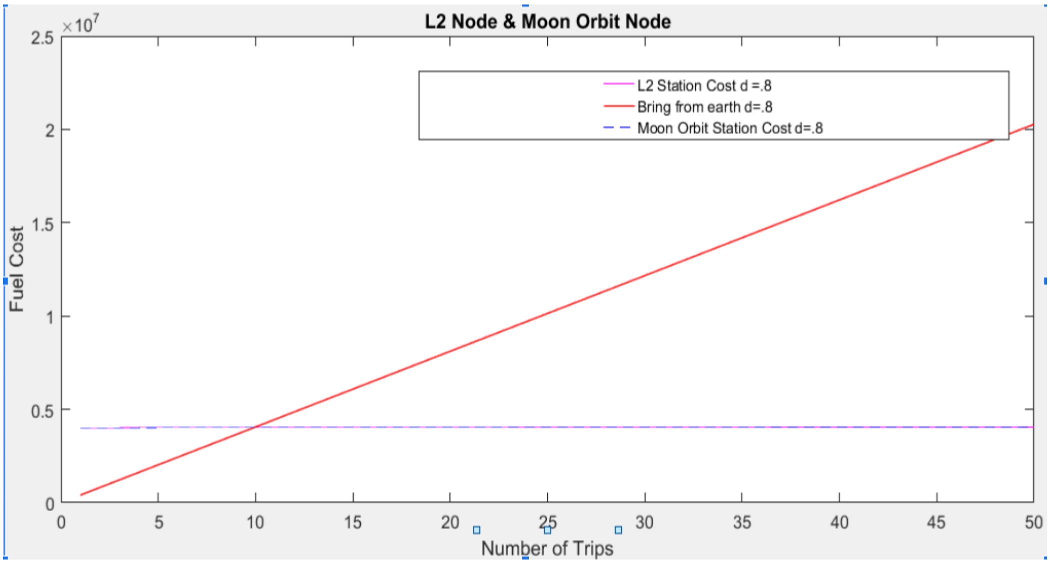

Figure 6: d=.08 The crossover point for investing ISRU at the destination is about 10 Trips

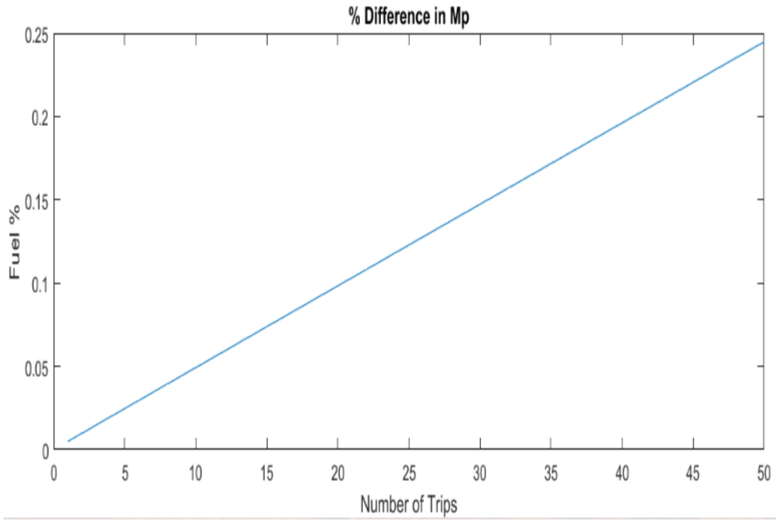

Figure 7: Percent Difference in Mp

difference is about .25 percent after 50 trips with the Moon base offering a cheaper trip. The small difference implies that either additional analysis should be conducted.

The first graph above conveys the crossover point with a lower inert mass. The lower inert mass means lower propellant costs because of the more efficient vehicle. The number of trips remains 10 because the calculation deals in ratios. This means the math works out so that no matter how efficient the vehicle or payload mass, the TER holds constant. The second graph above illustrates the percent difference in propellant burned. This value changes due to the lower inert mass. Here, 50 trips shows about a 6.5 percent savings in fuel from a Moon orbiting base.

Table 3: Transfer costs between each location with an inert mass of d=.04

Transfer (Per Trip)	Propellant Cost (MT)
Equipment	11.1
Moon-L2	.536
Moon-LLO	.353
Earth-Moon	11.2

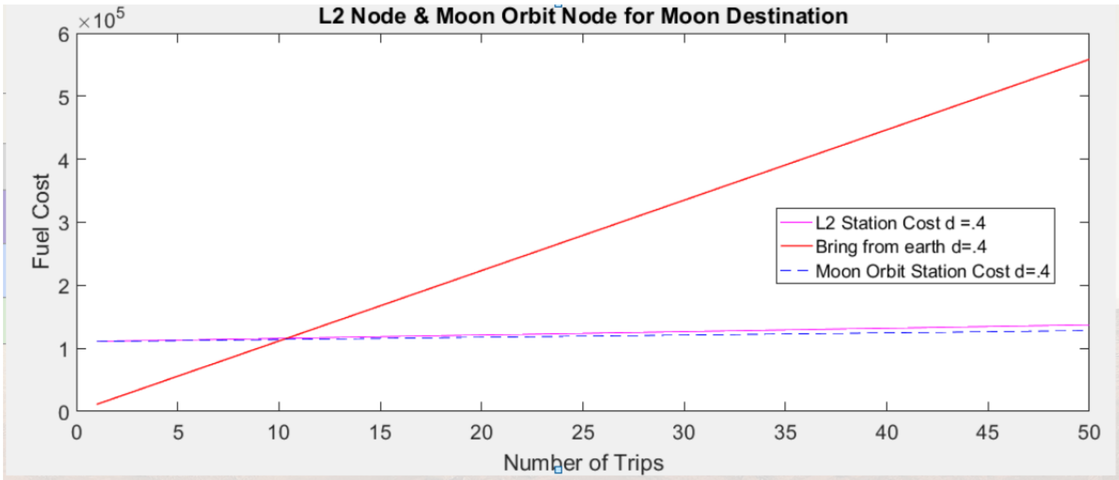

Figure 8: d=.04 The crossover point for investing ISRU at the destination is about 10 trips, showing how the scaling remains consistent no matter the efficiency of the vehicle.

5.3 Finding the Crossover Point Mars

This analysis describes the crossover point for an L2 and Moon orbiting base for Mars exploration. However, the following moon orbiting base and L2 base remain constant.

- ISRU, power and mining infrastructure sent to the Moon. Node exists in Moon Orbit
- ISRU, power and mining infrastructure sent to the Moon. Node exists in L2
- The payload is delivered from Earth with no node.

With the end goal of Mars exploration, the above table shows the propellant costs for an inert mass ratio of .04. The first graph shows the extreme benefits of a moon orbiting base. Even with all of the infrastructure invested to put fuel on the Moon, its always cheaper to have either a Moon orbiting or L2 node to deliver a payload of the same mass. However, it should be stated again that this analysis does not take time of flight into

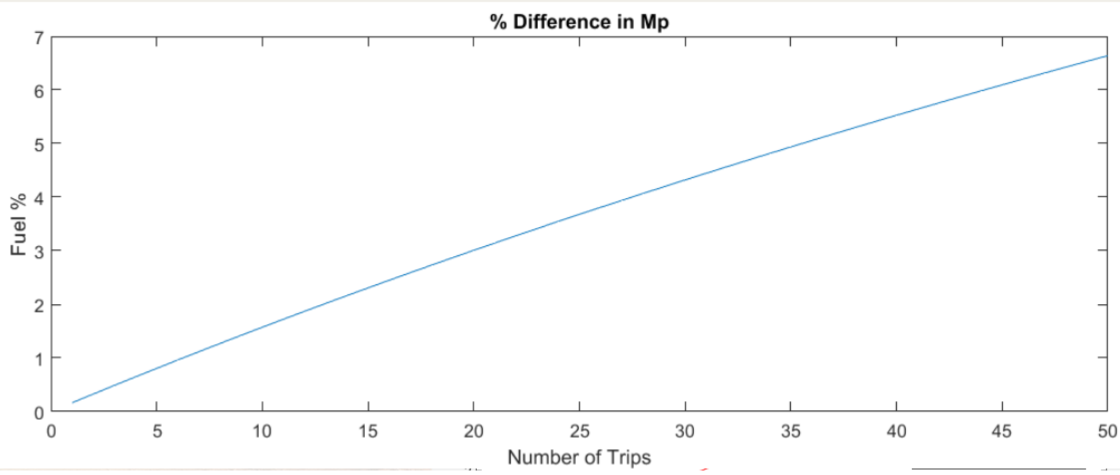

Figure 9: Percent Difference in Mp

Table 4: Propellant costs for propellant investment infrastructure on Mars with d=.04

Transfer (Per Trip)	Propellant Cost (MT)
Equipment	11.1
Moon-L2	1.63
Moon-LLO	2.27
Earth-Moon	17.2

account. These numbers still seem skeptical and further work will be done to validate and apply to different planets. Also, comparing the same size payload in both scenarios might give an unrealistic result because the it might be easier to deliver larger payloads from Earth and the node. More rigor should be placed in the infrastructure investment on the base like launch vehicles, refurbishment and maintenance area, storage tanks and other key pieces required for the node. The second graph showcases a 4.75 percent fuel savings in an L2 base over a Moon orbiting base after 10 trips which shows the highest advantage so far for the L2 base. So, if your end goal is just Moon exploration, you save more fuel from the Moon orbiting base; however, if the end goal is eventually Mars, the extra investment into the L2 base pays off rapidly.

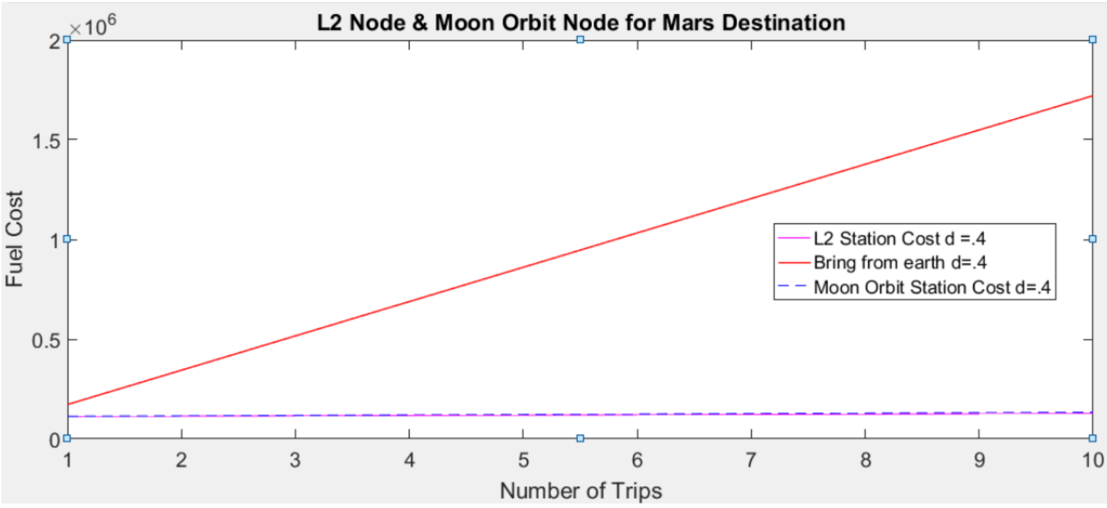

Figure 10: d=.04 Crossover Point

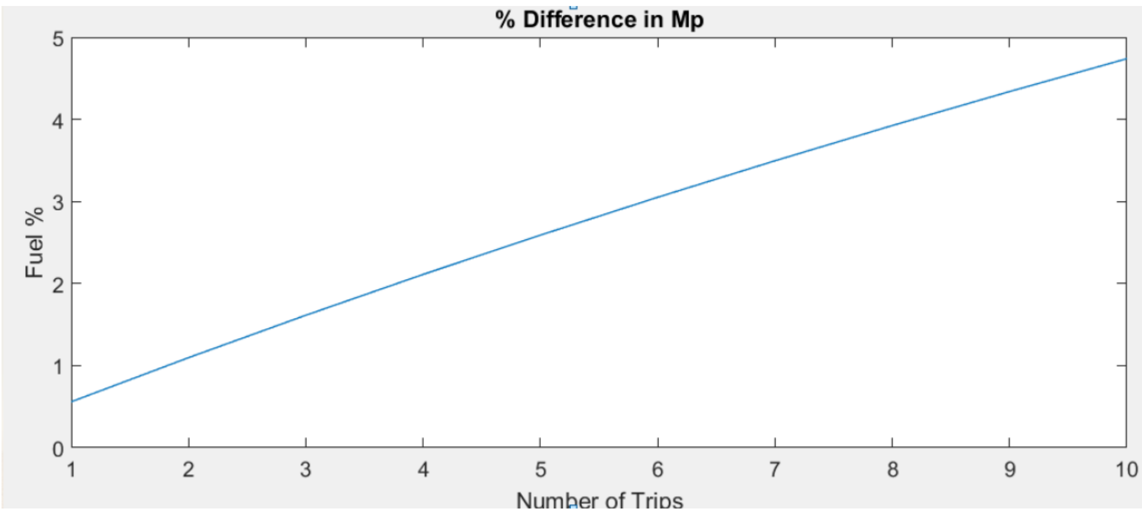

Figure 11: Percent Difference in Mp

6 Destination Function Development

6.1 Logistics Facility ConOps (Overall)

For the station to operate as a stepping stone for future infrastructure, it most support the near future operations while simultaneously preparing for the transfer to far future operations. To do this, the station must support NASA's goals of developing a LEO economy. The LEO economy is predicted from current investments and NASA expectations. From here, educated guesses and speculation are employed along with the forward station's developing logic to create the function development timeline.

6.2 LEO

Besides commercial transportation, a large portion of the LEO economy resides in research and in-space manufacturing **cite**. In the early stages of the LEO economy, the forward stations functions mimic the ISS besides operating in its orbit. Most of the required tasks were derived from NASA's needs. These include human factors research, next generation exploration ECLSS and ISRU testing, crew rendezvous, private research and in-space manufacturing. Supporting functions for this include a pressurized area, ECLSS system, solar panels, racks with power and data for research and a manufacturing area as dictated by the commercial entity. This will probably require extra power and volume in addition to a method to reload raw resources and export finished products as scaling increases. Supporting the in-space manufacturing research in the beginning will pay off later for the forward station. This is because it will enable the station to leverage progress completed towards cargo transfer and self-building later in the development timeline. This volume doubles for a general research area for conducting the year research quotas for fundamental science.

The second phase of the LEO economy is marked by a substantial increase in the LEO processes conducted by the forward station instead of the ISS. At this point, a 50-50 split of market share by the forward station and ISS are assumed. Since the market is growing, companies places around the world will want access. Depending on the needs of the market, the forward station will need to shift orbits to accommodate launch sites around the globe to allow other countries besides the countries with launch sites favorable to the ISS to have access. Frequent orbit maneuvers like these will require additional refueling missions and procedures when compared to the ISS. This facilities the need for amassing a fueling station in orbit to reduce the number of individual surface to orbit fuel deliveries. Lastly, since the forward station can receive cargo from around the globe, the need to deliver cargo around the globe naturally arises. These three functions call for a refueling, propellant storage and lander taxi system. If boil-off proof technology does not exist, then the need to produce the fuel in orbit will arise to support the growing demands of the LEO economy. Additionally, the crew rendezvous functions will continue to be the major burden of the ISS to volume of the forward station to be allocated for supporting the emerging markets in the LEO economy. In exchange for this, the functions mentioned above combined with taking over the non human factors essential research are the responsibility of the forward station. This allows non pressurized and human centered design to dominate the requirements of the forward station while the ISS handles the crew portion. However, the human factor designs seen in the first iteration can still exists, but in reduced capacity to support emergency shelter needs or repairing broken autonomous equipment.

The final step in the LEO economy development is marked by an overwhelming majority of market operations conducted by the forward station. At this point, a network of forward stations supporting the delivery of cargo, raw propellant resources and in-space manufactured products swarms LEO. Many stations are dedicated to autonomous, non human research or even empty hangars awaiting the delivery of a new in-orbit startup facility. The vision is a well established and proven ”railroad” system to LEO with a low cost of entry so new companies or even entirely new markets can utilize it and try to stake a claim in the bustling LEO economy. Another vital part is the that the logic described here is only enhanced by new, paradigm shifting technologies. For example, as Earth prepares to move the forward station economy to the Moon, all the technology researched and developed with the help of the forward station will likely be inexorably linked to the development of the station. This means humanity benefits from the capitalistic gains of private companies through the mutually beneficial development relationship described above. So, all the latest technology and improvements are included with the bus of stations sent to the Moon. The next section describes how this LEO economy timeline is applied to the Moon's propellant harvesting.

6.3 Mars

The transit part of the ConOps takes important pieces from the DRA5 to provide a baseline mission architecture. The Cargo MTVs are launched from several launch vehicles. Then, the propulsion stage, fuel tank and payload for both vehicles rendezvous in orbit before the final stretch to Mars. Once the cargo arrives at mars, the habitat and ISRU system are deployed. Verification of the Mars base and ISRU generation initiates the crew transfer. Two propulsion stages, the deep space habitat, Orion and an additional tank head to Mars. Once there, the crew descends to the surface to conduct the first mission. Once the mission is completed, the crew departs on the same vehicle back to Earth. Arriving on the surface in the Orion capsule.

The second part of the ConOps follows how the 3 major systems deploy and interact with Martian assets. Once the Cargo MTV arrives in Mars orbit, the payloads are deployed to the surface. The remaining parts of the vehicle stay in orbit until the ISRU unit is deployed.The payload shrouds deploy with the ISRU and Habitat on their unique landers. During the descent, the small payload platforms jettison away and fly across to predetermined areas on the surface. Each deploy their specific payloads ranging from crew supplies, beacons, science equipment or networking equipment. Once the landers touch ground, the habitat and ISRU facility are deployed. Both orbiting logistic stations descend to the surface and are refueled by the station. Each station removes one of their fuel tanks to be permanently used as a storage tank for the ISRU system. Then, one station ascends to orbit and awaits the next payload that needs to descent to the surface. Once that occurs, the orbiting station descends to the surface and the station on the surface ascends to orbit to repeat the process.

7 Forward Station Functions

7.1 PHASE 1

Research into NASA's short and mid terms plans for LEO is used to plan the trajectory of the forward station. Until a serious LEO economy starts and businesses in different sectors are turning a profit in LEO, the majority of the orbit's use is for NASA's research. NASA will be predominately operating in the ISS orbit with some servicing and satellite work for GPS. NASA will indefinitely conduct human factors research to continue to document and test the effects of micro gravity along with technology demonstrations for understanding system life cycles and analog testing. Its predicted NASA will continue to conduct this research well past the point of a booming LEO economy or even full exploration of Mars. These baseline functions will always be available from NASA and will be carried out by the ISS and most likely any foreseeable successors. This means the forward logistics station will not take over or assist in these functions because the logistics for these actions will not develop in any monumental way that needs assistance.

Private research projects are the beginning of the LEO economy. Non research projects that can be conducted in the same station will be available from the yearly quota of projects which will labeled as Fundamental Science. Projects in past consisted mostly of pharmaceutical and in-space manufacturing methods **CITE**. The equipment to support these systems consists of power and data, pressurized volumes, storage transfer between the inside and outside and autonomous manipulators for non human operations. Additionally, the forward stations can leverage the technology improvements from in-space manufacturing from the commercial endeavors for later exploration. This is another example of the forward station cooperating with the developing of the technology simultaneously as the forward station develops for better synergy as the station moves to further destinations.

In the early stages of the LEO economy, the forward stations functions mimic the ISS besides operating in its orbit. Most of the required tasks were derived from NASA's needs. These include human factors research, next generation exploration ECLSS and

ISRU testing, crew rendezvous, private research and in-space manufacturing. So, the first iteration of the forward station needs to accommodate these through a traditional ISS module design. It will need a pressurized area, ECLSS system, solar panels, racks with power and data for research and a manufacturing area as dictated by the commercial entity. This will probably require extra power and volume in addition to a method to reload raw resources and export finished products as scaling increases. Supporting the in-space manufacturing research in the beginning will pay off later for the forward station. This is because it will enable the station to leverage progress completed towards cargo transfer and self-building later in the development timeline.

Research projects that have a definitive end goal that directly supports the exploration and deep space habitation efforts will be supported by the forward logistics station. This is because the forward station can utilize them in a multipurpose fashion. By outfitting the forward stations with the latest iteration of these systems, the Exploration ECLSS systems and Forward Logistics Evolutionary Design are simultaneously being demonstrated. This is the same technology that will be used on Mars, so having it evolve with the infrastructure that delivers, deploys and utilizes it is key to the success of both systems. Placing the Expo ECLSS systems in the forward station where it makes sense. The same baseline infrastructure that supports private research.

Crew Rendezvous is a critical part of LEO and ISS orbit, but human access to other orbits will require the forward logistics station to support this function to deliver people to deep space, transfer or other orbiting stations without transferring to the ISS. Also, demonstrating this function early allows the technology to develop for use on the Moon, L2 and Mars. This means the early forward station will have an airlock, pressurized interior, ECLSS system to support a small crew for a limited time. This support will be removed or adapted as a temporary, emergency shelter for crew away from LEO.

7.2 PHASE 2

The second phase of the LEO economy is marked by a substantial increase in the LEO processes conducted by the forward station instead of the ISS. The successful markets will have a small hand in how the forward logistics station develops on LEO.

However, the core logic that shapes the station is consistent. At this point, a 25-75 split of market share by the forward station and ISS are assumed. Since the market is growing, companies places around the world will want access. The forward station can accommodate this through an advanced propulsion system, in-orbit refueling and scaling. Depending on the needs of the market, the forward station will need to shift orbits to accommodate launch sites around the globe to allow other countries besides the countries with launch sites favorable to the ISS to have access. Frequent orbit maneuvers like these will require additional refueling missions and procedures when compared to the ISS. This facilities the need for amassing a fueling station in orbit to reduce the number of individual surface to orbit fuel deliveries. Lastly, since the forward station can receive cargo from around the globe, the need to deliver cargo around the globe naturally arises. These three functions call for a refueling, propellant storage and lander taxi system. If boil-off proof technology does not exist, then the need to produce the fuel in orbit will arise to support the growing demands of the LEO economy. This pushes

During this phase, all the previous research is still occurring, but the focus of the forward station is supporting the LEO economy.

7.3 PHASE 3

This phase assumes the LEO economy goes global with many countries accessing it at once and new profitable industries outside of manufacturing and transportation are born. At this point, its difficult to make an educated guess about the state of a Leo economy, so its assumed that the forward station in LEO scales to support the growing industries. Meanwhile, the push for missions on other planets begins. The ISRU, Power, Habitat, Forward Station, Taxi and mining equipment tested on Earth and LEO is sent the Moon through a slow moving transfer vehicle. This forward station has the ancestry leanings from its predecessor and equipped with all the necessary functions to support the Moon mission and further expansion while stripping the functions only needed in the LEO economy.

7.4 PHASE 4

Once deployed to the moon. The processes described in the Moon Concept of Operations begins. The forward station is responsible for facilitating all cargo transfer, vehicle docking, payload deliver and transfer through the lander and supporting communications infrastructure. The key new technologies that are developed during this phase are in orbit fuel processing and cryogenic fuel storage that's immune or highly resistant to boil off. Sometime later, the operation shifts its focus to storing raw fuel resources at L2 to leverage the gravity well. Then, this important station paves the way for the LEO economy to relatively cheaply expand their operations to the Moon. As the future unknown economy at the Moon develops, this process can be repeated as mankind extends its reach. The logic is simple and can be amended to accommodate any paradigm shifting technologies.

7.4.1 Forward Station Requirements

The forward station needs to facilitate the evolution of each destination along with the functions needed to transition from one destination to another or to the next phase of a single destination. How functions change, add or are removed is briefly explained again, but the focus is to show the transition of each function in the forward station's lifetime.

The initial functions of the station should coincide with what NASA wants. Almost all future space development from the United States depends on how NASA allocates its funding for the foreseeable future. Commercial industries are growing, but almost all of their money comes from NASA funding. Therefore, its important to draw upon NASA's future plans as a starting place for the forward station. The forward station leverages the gains from commercial industry and NASA's research to propel the space program into a self-sustaining, step-by-step transition.

7.4.2 Phase 1 - LEO Economy and Research

The initial LEO forward station focuses as a research station. It operates in the Earth-LEO system. The majority of the structure is a pressurized shell similar to the

ISS since its performing ISS functions. It would have the same autonomous docking and berthing systems on board the ISS. Also, this station includes traditional solar panels and radiators to take advantage of the solar power in LEO. Lastly, a new addition would be the internal accommodations for the in-space manufacturing facility and resupply. The nuance for this layout depends on the company and markets that shape the facility.

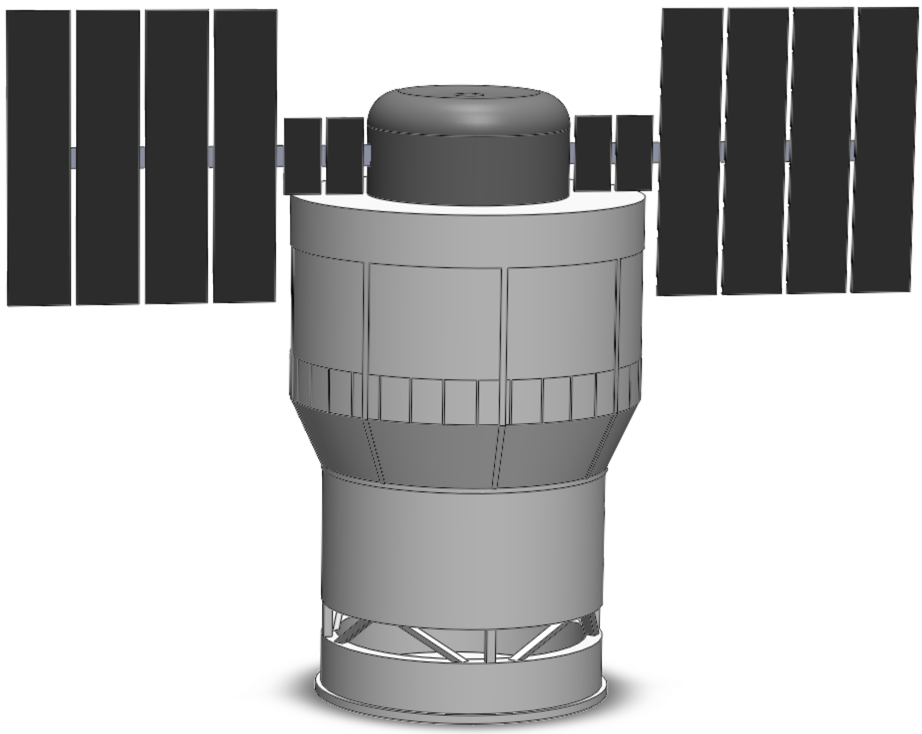

Figure 12: The first iteration of the forward station designed for ISS functions

7.4.3 Phase 2 - LEO Economy Booms

The growing LEO economy can be massaged by a forward station that can support launch sites around the world. The node must accommodate all because space programs around the globe will need access from their different launch sites. This opens up the market for more countries to support it as opposed to the ISS remaining in one orbit. Additionally, with more funding and support behind the forward station, additional technology testing can be done including the lander and vehicle refueling. Transfer vehicles around the globe could be launched into orbit, dock with the forward station, refuel and begin their mission beyond LEO. Also, the non human factors research and manufacturing can shift to the forward station while the human factors research can remain on LEO. This allows the forward station to remove the pressurized volume in exchange for versatile unpressurized volume to support the new technology and emerging markets. This can include docking ports for a vehicle hanger and the remaining pressurized volume can be used as a smaller airlock or an emergency shelter for crew.

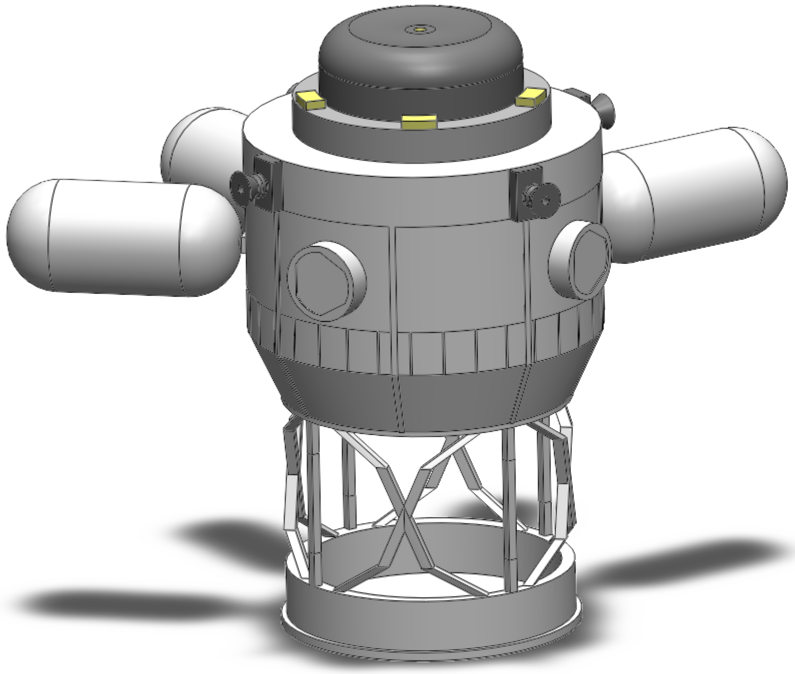

Figure 13: The second iteration of the forward station with expanded capabilities like nuclear power

7.4.4 Phase 3 - Moon L2 Beyond

At this point, fuel is constantly being produced and delivered on the Moon. The forward station can deliver the fuel to a holding depot at L2. Having boil-off proof storage would allow for a stockpile of cryogenic fuel to await transfer vehicles. Additionally, the forward station can support communication and navigation infrastructure to support surface operations. At this point, the LEO economy can begin to expand to the Moon as their is a clear logistics train available from LEO. The same functions would be copied to Mars and ideally the space economy grows to envelop that planet.

This can repeat as humanity extends its grasp.

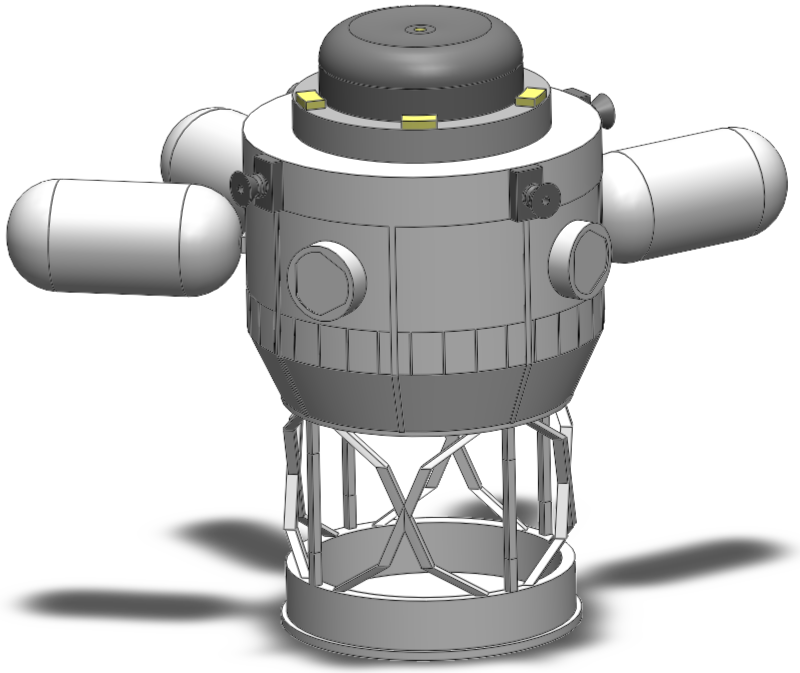

Figure 14: The final iteration of the forward station with the lander taxi

The main functions derived from the previous research can be analyzed further to derive their analogous space application. The first function of the node is to operate as a staging point for further exploration. This includes operations for capturing spacecraft, refueling, cargo transfer and replenishing life support system resources. All of these serve to extend the life of the craft to reach a far destination that is usually out of reach. Another important function is the ability to capture any discarded equipment or vehicles for reuse. A huge part of becoming a self sufficient craft requires the ability to minimize refuse through strategic re-purposing and reuse of resources. Additionally, the node must facilitate cargo transfer cargo between docked orbiting craft and a decent/ascent vehicle. The ability to freely maneuver, store and unpack cargo of various sizes and pressurization needs is imperative to the staging point operations. An analogous situation to understanding these functions is this: Imagine a company wants to build a mining operation in a continent around the globe in a dangerous and unexplored area. To support the mining operation, they need the mining infrastructure, staff, food, maintenance abilities, sleeping areas. To bring this infrastructure, an initial investment of infrastructure is required. This project focuses on the infrastructure needed to bring the infrastructure needed to complete a mission.

The node's success can be improved through some secondary functions. These include establishing a communications network, a global position and navigation system and caching resources. The communications network allows rapid and clear communication across the destinations surface. The ability to quickly relay messages across large distances is critical to the future success of the node. Secondly, the global position and navigation system facilitates autonomous and manual travel at the destination. This makes the exploration and daily tasks operations through marking the shortest, but safest paths between points of interest. Lastly, the ability to cache resources across the surface of a destination increases the robustness of all exploration and building tasks across the surface. Essentially caches of important resources scattered across the surface allows visitors to explore farther, lighter and safer.

Diving into the first criteria revealed additional functions for the node related to fuel storage and transfer. The criteria took a close look at the fuel costs for moving and storing propellant at different locations around the Solar System. This requires a cryogenic propellant storage mechanism to avoid boil off. The need to move fuel between points of interest drives the need for a fuel transfer vehicle with a nuanced interface for human and robotic manipulation.

8 Conclusion

1. The background research of this paper resides in the logistical development of large infrastructure operations like overseas military deployment operations and Antarctic exploration.

2. By adapting the overlapping key strategies from these large scale logistic efforts to space architecture, space exploration can leverage the successful strategies to amplify its growth.

3. The adaptations were then applied to develop a long term space exploration plan to derive functions for a conceptual logistic station.

4. Then, the case for a logistical development path is made through data analysis of delta-v and In-Situ Resource Utilization (ISRU) technology. The logistics station operates mainly as a fuel depot for this study.

5. Additional analysis examines the functions of each space destination to look for common threads and important changes of destinations over time that could require or facilitate the need for major changes in the logistics station.

6. The conclusions from the previous section feed the requirements for the logistical nodes changes. It still servers as a depot, but secondary functions arise depending on the needs at the time and location.

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