Mission to Mars: Sustaining Human Life Through Food

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Author

Matthew Coulter
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On my honor as a University Student, I have neither given nor received unauthorized aid
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Approved ____ Date __________
Rider Foley, Department of Engineering and Society

Introduction

Mankind has always been characterized by an innate desire to explore. Whether it was a journey to just beyond the horizon or a voyage across the sea, our penchant for exploration has defined the history of our species. Therefore, it is no surprise that space–the Final Frontier–has captured the imagination and curiosity of people around the world for the past 60 years. Space travel is not easy. It is expensive, time-consuming, and dangerous. Despite the challenges, mankind has managed to establish an orbiting laboratory in the International Space Station and has even set foot on the Moon. However, there is much we have yet to accomplish. One of the most intriguing ideas for mankind's next step in space is a journey to Mars. If there is indeed water on Mars as evidence suggests, then it is conceivable there could be microbial life as well (Redd, 2018). This could be our first significant step in answering the enduring question, "Are we alone?"

As you read this, automated rovers are already exploring the Martian surface. While these machines provide us with a plethora of new data and information, they are no equal substitute for actual human researchers on the ground. Sending human explorers to Mars is a daunting task – the journey alone presents a vast array of challenges and is expected to take at least 6 months. While there are many logistical issues to be tackled on a long-distance space flight, one of the most urgent is the question of food. What will the human crew eat during this time? How will they prepare the food? Will space affect the chemical nature of the food? All of these questions must be answered before mankind can attempt a voyage to Mars.

There are two principal ways in which astronauts could eat on a Martian mission. First, they could consume pre-packaged meals from a set menu devised on Earth. This is the method that NASA has used in all its space shuttle missions up to this point. The other option is to rely on a hydroponic agriculture system to grow the crops in space. While thorough research in recent years has shown the hydroponic method of growing plants to be both safe and efficient, it has never been heavily relied upon in a space setting. There are certainly benefits and drawbacks to both methods, but it is crucial that space agencies like NASA make a decision soon on how to feed astronauts in space so they can properly focus their efforts and resources. Mankind should utilize a hydroponic agricultural solution in order to sustain human life on Mars.

Case Context

In order to fully grasp the complications that arise when considering feeding humans in space, we must also thoroughly comprehend the underlying technology. The shelf life for the food currently used aboard the International Space Station (ISS) is one year – a mission to Mars would require food with a shelf life of 5 to 7 years. This requires substantial alterations to the chemical composition of the food, as nutrients and vitamins tend to decay over time. This degeneration not only leaves the food with a lower nutritional value, but also changes the color and taste of the substance which can render it unappealing to the astronauts (Reynolds, 2018). This problem can be solved by frontloading the food with nutrients in a process called fortification. The nutrients in food naturally decay over time, so fortification ensures that when the crew is ready to consume an item, it will still contain the required amount of nutritional value.

Hydroponics, while advantageous in many ways when compared to pre-packaged meals, are much more technically complicated. Consider the Mars Lunar Greenhouse, a bioregenerative life support system developed at the University of Arizona. This collapsible system uses plastic sleeves to carry a nutrient-solution to the plants in their hydroponic trays while LED lamps provide sufficient light. A computer-automated system controls the flow of water to ensure maximum efficiency, and an external composter recycles plant and human waste back into the system (Furfaro et al., 2017). With all these moving and interrelated parts, the risk of a system failure drastically increases. If astronauts in space are relying on the hydroponic unit as their primary source of food, any failure could be catastrophic for both the mission and the crew.

Experimentation with hydroponic systems for use in space is already underway. The ISS currently houses a vegetable production system known as Veggie, which has already grown a number of plants successfully in Earth's orbit. The plants are selected for a wide variety of criteria including dietary value (lettuce and cabbage), psychological effect (zinnia flowers), and protection from deep space radiation, such as berries, beans, and other antioxidant-rich foods (Heiney, 2019). While this system is being used for testing purposes rather than feeding the crew, successfully growing hydroponic crops in space is a critical first step along the path to a hydroponically-sustained mission.

STS Topic

I will utilize the Social Construction of Technology (SCOT) framework to examine aspects of two methods proposed to feed deep space astronauts – pre-packaged meals created on Earth and fresh food grown on Mars. First, let us examine the SCOT framework and how it applies to this problem. The SCOT theory argues that it is people who dictate the terms of how a technology is designed, built, and implemented rather than the technology itself. This notion arose in direct opposition to the theory of technological determinism and supports the idea that human wants and needs shape the technology we see today rather than the other way around. (Pinch & Bijker, 1984). An important concept to keep in mind is flexible interpretation, which essentially means that a technological artifact will have different meanings to different social groups. The rest of this section will detail the ways that food production for a Mars exploration mission can be viewed through the SCOT lens.

The criteria for determining which food production method is superior is ultimately determined by the astronauts. Considering they are the ones depending on this food for survival, one can safely say they are the most relevant social group within the problem framework. The base criterion for their food supply is survival. However, it is not enough for the crew to merely survive – they are dramatically pushing the boundaries of mankind’s knowledge and skill, so their diet must allow them to thrive. Framing this problem within the SCOT theory reveals how the unique needs of humans in outer space are shaping the technological solutions involved in feeding astronauts. There are other stakeholders in this situation as well such as NASA, private space agencies like SpaceX, and the future generations of mankind.

The traditional method of feeding astronauts is through pre-packaging a mass quantity of NASA-approved meals on Earth and sending them into space with the crew. One challenge of creating an astronaut’s menu is to include an adequate variety of foods. A phenomenon known as menu fatigue may occur if there is not sufficient diversity in a person’s eating habits, causing them to eat only enough to survive, but not to thrive. This is unacceptable for an astronaut on a critical mission to Mars as they must be operating at peak capability at all times (Fecht, 2019). Therefore, the menu must contain a diverse set of familiar foods that can be found on Earth as opposed to strictly nutrients and vitamins (such as a Soylent shake). The NASA team works hard to prevent menu fatigue by crafting a menu of over 200 carefully engineered food options (NASA, 2019).

Using hydroponic greenhouses to grow fresh vegetables and fruits offers a more sustainable but complicated means of feeding future Mars explorers. One advantage of a hydroponic system is the familiarity of the produced crops. Over the course of 40 years of manned space missions, NASA researchers have observed that the mission's menu has a significant psychological impact on the crew members. The right food can serve as a comforting element in an unfamiliar and highly stressful environment, which is especially important on long-duration missions such as a journey to Mars (Perchonok, 2019). Allowing astronauts access to fresh crops nearly identical to those that they would encounter on Earth would likely go a long way towards boosting morale on deep-space missions.

Another benefit of growing crops in a hydroponic system is that it could serve as a form of horticultural therapy for the crew. A practice that uses plants and gardening to improve mental and physical health, horticultural therapy has been the subject of numerous experiments and proven to reduce feelings of stress, anger, and anxiety while promoting increased relaxation and sense of community (Hayashi et al., 2008). This could be an invaluable tool for human beings traveling to Mars, as they will undoubtedly face many stressors and will have a limited number of ways to relieve negative feelings in the confined spacecraft. Examining the issue of food production in space through the SCOT theory shows how the unique requirements of maintaining human health off of Earth have shaped the technologies behind both pre-packaged space food and potential hydroponic systems.

Research Question and Methods

In order to produce enough food to sustain human life on Mars, should mankind rely on Pre-Packaged Meals (PPM) from Earth or growing food on Mars? This question is of the utmost importance, as the time to prepare for a mission of such massive scope is right now. Space agencies need to allocate their resources towards the best method of food production, whether that be revamping the existing model of PPM or experimenting with new methods of hydroponic crop cultivation. To answer this question, I collected mainly secondary evidence on the topic such as prior literature, agency reports, and online resources. This constituted the bulk of my data, as I was wary of relying too heavily on primary evidence considering the specialized nature of working in the space industry and my current lack of connections in that field.

Once adequate evidence was collected, I analyzed it using the case comparisons method. Essentially all space expeditions up to this point could be considered case studies for the PPM method. Sources I found particularly helpful during my research on the production of food using PPM were works on the official NASA website by Perchonok (2019), Wild (2018), and Smith et al. (2015). I also found the research by Pelligra and Edemekong (2019) on health in aerospace medicine to be informative. When searching for information regarding the current and future use of hydroponics in space, Herridge (2016) provided illuminating content on NASA's official page. Published journal articles by Brion et al. (1994) and Jones et al. (2014) were also quite helpful. Articles by Preston (2015) and Toothman (2020) helped fill the gaps in my understanding.

The two options have both arisen from human needs and desires within the SCOT framework, and these have changed over time resulting in different systems. As far as evaluative analysis, I conducted risk identification and management on both food production alternatives. I employed the hierarchical holographic modeling (HHM) technique to gather and synthesize the vast amount of information associated with the implementation of a food production system on a journey to Mars. HHM allows the analyst to view large-scale systems from a number of different decompositions, or perspectives. By dividing potential sources of risk into various perspectives, each with its own subsets, one develops a better understanding of often-intimidating major systems and their accompanying risks (Lambert et al., 2001). It is important to note that I relied heavily on Lambert's HHM methodology, using it as a template while conducting my risk analysis and then adapting it to fit the unique challenges of producing food in space.

This process involved first identifying sources of risk and including them in a master list for each method. Each source of risk was then attributed to the three decompositions in Figure 1 that were most applicable to that risk. I identified 24 sources of risk identified for PPM and 20 sources of risk for hydroponics. I selected 5 broad categories under which sources of risk fall: program consequence, management of change, temporal, geographical, and functional. There are three to five decompositions under each of these perspectives in order to further specify a particular risk. For example, the risk stemming from the unknown properties of root substrate in

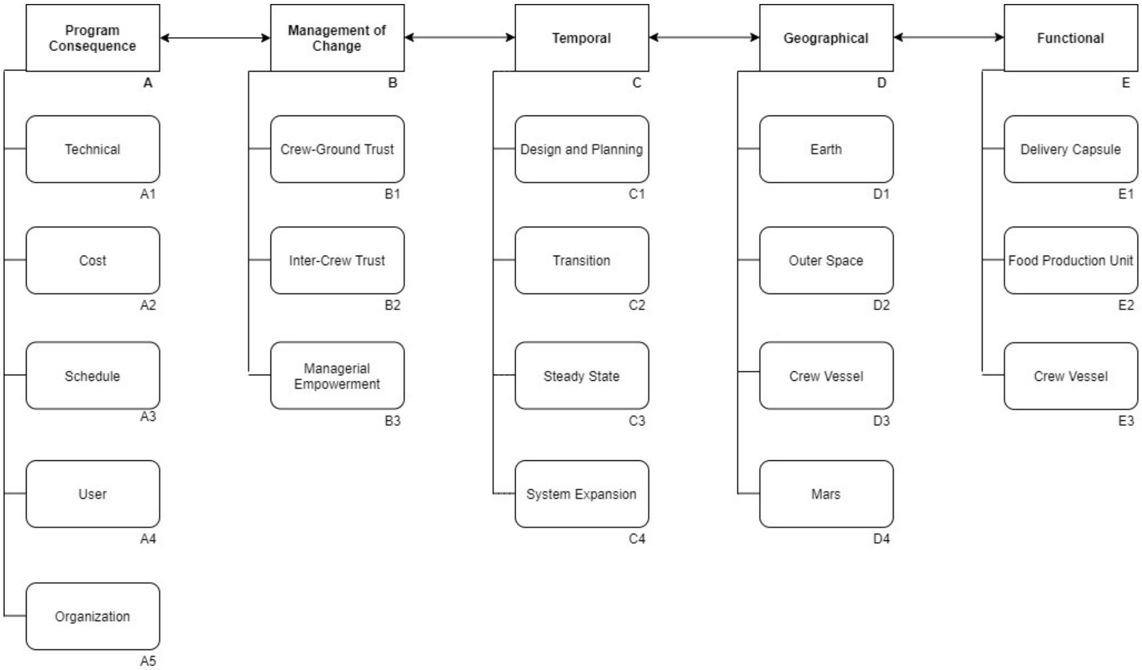

Figure 1. Hierarchical Holographic Model (HHM) for identifying risks associated with food production in space.

microgravity was attributed to A1 (technical), C3 (steady state), and E2 (food production unit. The matches between the master list and the HHM decompositions were then analyzed for potential trends.

Once the risks of both alternatives were identified, I consolidated the large master lists into a handful of condensed risk groups. These grouping were made the same for both alternatives for easier comparison. Next, I formed a set of specific criteria to rank potential sources of risk. I then ranked each consolidated risk group, for both alternatives, according to the defined criteria. At this point, adequate analysis had been conducted that conclusions could be drawn and conditional recommendations issued. I have taken special care to ensure that the perspectives and criteria involved in my risk analysis are things important to human considerations – SCOT states that these technologies have been built to meet the different requirements determined by various social groups, so their associated risks will be judged and evaluated in a similar manner.

Results

In order to sustain human life on the journey to Mars and on the planet itself, mankind should focus on growing crops with the use of soilless methods such as hydroponics. The risk analysis I conducted revealed that requiring an astronaut crew to grow crops itself presents less overall risk. This is primarily because the crew will be granted the autonomy to sustain itself. While help from Earth-ridden space agencies is obviously very helpful at this point in space exploration, the risks presented by a dependency on PPM increase dramatically as the mission takes the crew further and further away from Earth. Growing crops in space is considered the riskier alternative today because the technology is still relatively young – as techniques and equipment become more advanced in the near future, the use of large-scale hydroponics in space will become increasingly feasible.

Figures 2 and 3 display the number of matches between the hierarchical risk model and the master list of all sources of risk for the PPM and hydroponic methods, respectively. One important distinction between the two charts is that there is significantly less geographical risk associated with the hydroponic method. The PPM method involves risk at every geographical level and is particularly precarious in outer space and on Mars, while hydroponics has only a relatively small identified risk at these two locations.

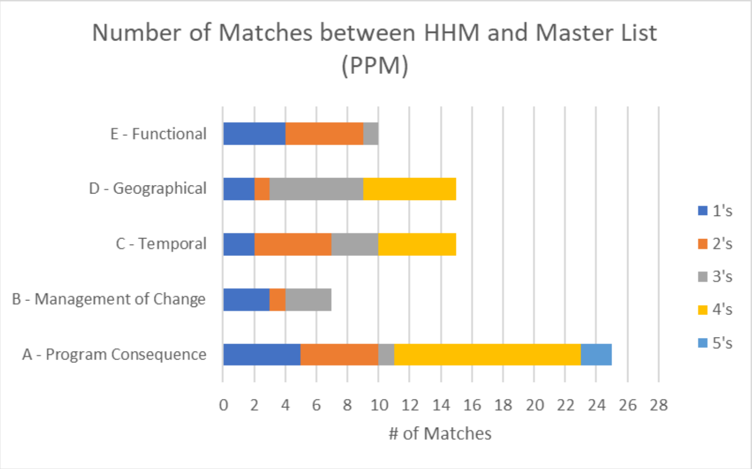

Figure 3. Chart displaying matches between HHM decompositions and master list risk sources for the PPM method.

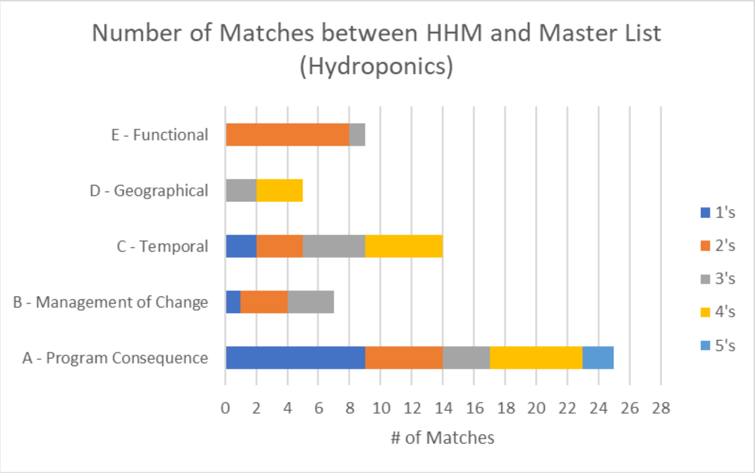

Figure 2. Chart displaying matches between HHM decompositions and master list risk sources for the hydroponic method.

Figures 4 and 5 reveal the distribution of matches within the different perspectives for each alternative. One can see that within Perspective A, Program Consequence, there is a discrepancy in the risk distribution between methods. PPM poses a much higher risk to the user, while hydroponics has significantly more risk associated with technology. Other important differences are that within

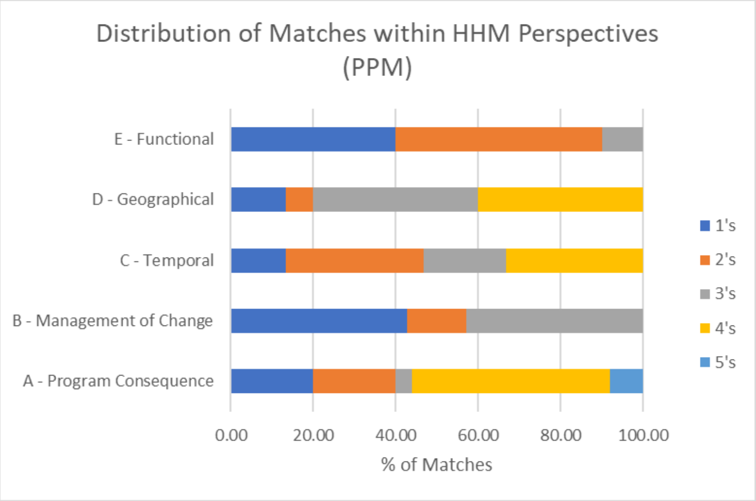

Figure 4. Chart displaying distribution of matches within different HHM perspectives for the PPM method.

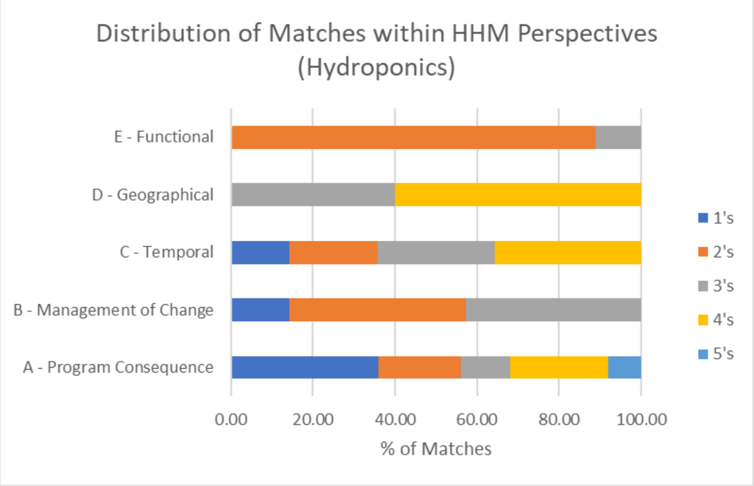

Figure 5. Chart displaying distribution of matches within different HHM perspectives for the hydroponic method.

Management of Change, trust between the astronaut grew and ground services poses a much higher risk for the PPM method. Meanwhile, the hydroponic method places a lot more strain on trust between crew members. This makes sense when considering the requirements of each alternative – PPM demands an extraordinarily high level of cooperation and communication between team members in space/Mars and on Earth, while hydroponics requires each crew member do his or her part in growing, protecting, and harvesting the essential crops. One can also see that the distribution of risk within the Functional perspective is heavily concentrated upon the food production unit for hydroponics, while PPM must account for potential complications with the food delivery capsule (whether that is being sent to the crew vessel of the Marian surface).

The next step in my risk analysis was to consolidate the large number of risk sources in both master lists into a handful of general categories. Table 1 shows the name and description of these consolidated risks, as well as the number of associated risks from each master list. Food generates a significantly higher level of concern in the PPM method as opposed to the hydroponic method. However, the technology behind hydroponics has more risk sources than that of PPM – this difference is likely more significant than shown, but appears less drastic due to the smaller number of overall risks listed in the hydroponic master list.

Risk Group	**Definition**	**# of Risks in Master List (PPF)**	**# of Risks in Master List (Hydroponics)**
Equipment	Risks associated with operation, reliability, and excess/lack of equipment	6	7
Food	The quality and quantity of available food and any issues resulting from those factors	11	6
Astronaut Daily Life	Problems stemming from the routine of astronauts both in space and on Mars	3	4
Space Environment	Risks caused by the hostile environment of outer space and Mars	4	3

Table 1. Consolidated risk groups encompassing all sources of risk in both master lists.

After creating a manageable number of distinct risk categories to work with, I devised criteria to evaluate each risk group for both alternatives. I used three main criteria: program risk, user risk, and risk mitigation. Program risk was further divided into expected impact and catastrophic impact. Action horizon and inefficacy made up the larger category of risk mitigation. Within each subcategory, the risk was evaluated to be either low, moderate, or high. These categories were adapted from HHM methodology and tailored to the distinct topic of food production in space, and can be seen below in Figure 6 (Lambert et al., 2001). The specific definitions of each criteria may be observed in Table 2.

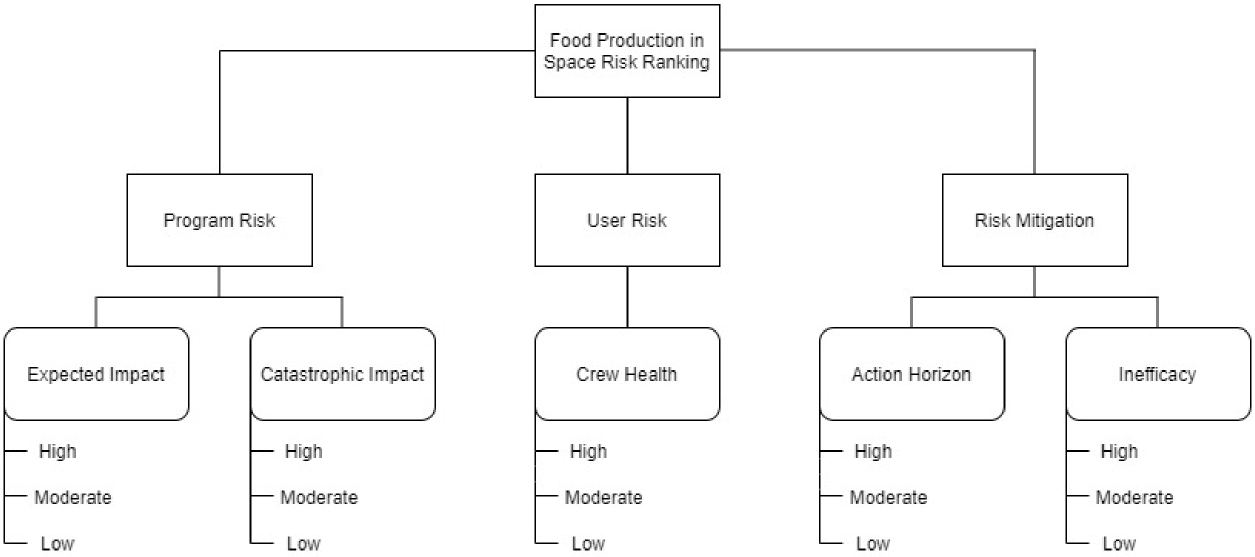

Figure 6. Breakdown of the five criteria used to evaluate risk.

Program Risk	**Expected Impact**	**Catastrophic Impact**
High	Expected that cost and/or schedule are impacted across the program	Irreparable loss of program capability in the worst case
Moderate	Expected that cost and/or schedule are impacted in certain program segments	Severe impacts to cost and/or schedule across the program in the worst case
Low	Expected that there is no major impact on cost or schedule	Severe impacts to cost and/or schedule in program segments in the worst case
User Risk	**Crew Health**	
High	Probable that crew members face severe health issues as a result of mission (including loss of life)	
Moderate	Possible that crew members face significant health issues as a result of mission	
Low	Unlikely that crew members experience long-lasting detriments to health as a result of mission	
Risk Mitigation	**Action Horizon**	**Inefficacy**
High	Less than 90 days available for initiation of risk reduction strategies	Risk cannot be mitigated internally
Moderate	Less than one year available for initiation of risk reduction strategies	Risk can be partially mitigated internally
Low	More than one year available for initiation of risk reduction strategies	Risk can be completely mitigated internally

Table 2. Definitions for each level of risk for all criteria.

The final step in my risk analysis was to rank each of the four different consolidated risk groups (equipment, food, astronaut daily life, and space environment) according to the five criteria given above. Tables 3 and 4 show the results of these rankings for both the PPM method and the hydroponic method. Here one can see that hydroponic equipment presents the riskiest component among both alternatives. However, risk sources from food have significantly less impact on the hydroponic method as opposed to that of PPM. The former also faces slightly less risk in from the outer space environment than the latter. In summary, I recommend pursuing the hydroponic method to produce food for a future voyage to Mars. While the technology aspect poses a significant source of risk, a concentrated effort in research and development effort will quickly reduce that area of concern and reveal the hydroponic method to be the space food of the future.

Pre-packaged Meals	**Expected Impact**	**Catastrophic Impact**	**Crew Health**	**Action Horizon**	**Inefficacy**	**AVERAGE RISK**
Equipment	2	3	2	2	1	2
Food	3	3	3	3	1	2.6
Astronaut Daily Life	1	3	3	1	3	2.2
Space Environment	2	3	2	1	1	1.8

Table 3. Ranking risk categories according to outlined criteria for the PPM method (1 = Low, 2 = Moderate, 3 = High).

Hydroponics	**Expected Impact**	**Catastrophic Impact**	**Crew Health**	**Action Horizon**	**Inefficacy**	**AVERAGE RISK**
Equipment	3	3	3	3	2	2.8
Food	2	3	2	2	1	2
Astronaut Daily Life	2	3	2	1	3	2.2
Space Environment	1	3	2	1	1	1.6

Table 4. Ranking risk categories according to outlined criteria for the hydroponic method (1 = Low, 2 = Moderate, 3 = High).

Discussion

The above risk analysis revealed that the PPM method presented a high level of risk when it came to the actual food, while risk in the hydroponic method mainly stemmed from the advanced equipment required for proper use. PPM was also slightly riskier than hydroponics when considering the unique demands of an outer space environment. The risk posed by astronaut daily life for each method was estimated to be the same. It is important to note that the use of hydroponics in space is still a relatively new development in space, while PPM were used to feed astronauts on some of the earliest space missions. When considering these results within the SCOT framework, one can rationalize the continued research of hydroponics as an astronaut feeding method. The significantly higher risks posed by hydroponic equipment are largely a result of the concept's infancy – it was developed in response to human physiological and psychological demands during increasingly long-duration space missions. The nature of space missions, specifically their length, is changing. This presents engineers with a new set of challenges in keeping astronauts healthy, so it makes sense that the food production technology used on these long missions must adapt along with other aspects of the mission as a result of human needs.

One principal limitation to my analysis is that this research was conducted individually. In order for the HHM methodology to be truly impactful, there must be a team of risk analysts working together to ensure that all possible problems and scenarios are accounted for. Additionally, it would be ideal to use subject matter experts, such as NASA scientists or astronauts themselves, to construct the comprehensive master list of sources of risk. Another notable restriction in my research is that there is relatively very little data regarding the use of any food production method in space. It is true that the PPM has been successfully utilized in missions to space, but there have been so few flights in space explorations short history that the data set is still relatively small. Hydroponics presents an even greater statistical challenge, as it has never been used as a primary means of feeding an astronaut crew in space.

In the future, I would start my actual research earlier. I enjoy writing and feel confident in my ability to construct meaningful narratives from my research, but actually obtaining all the data and conducting analysis is another matter altogether. While I don't consider myself inept in those tasks, I underestimated the amount of time and effort it would require given the unique nature of my topic. As mentioned earlier, the limited data on space ventures in general means that one must get creative when it comes to conducting a meaningful data analysis. I would also make more of an effort to obtain primary sources of information and data. While it is likely that I would not have been able to find anyone in the space industry who would be both willing to speak with me and able to provide relevant information on my topic, I will never know because I did not make an attempt.

I will likely not use my research to advance my engineering practice in the foreseeable future. Because I will be going to Naval Air Station Pensacola upon graduation to begin training as a Naval Aviator, I am not sure I will be able to put my research into practice right away. However, my interest in space remains quite genuine. The path to becoming an astronaut is challenging and statistically highly unlikely. That being said, Naval Aviation is one of the primary career paths to ultimately securing a spot in the NASA Astronaut Corps. If I choose to pursue that route and manage to succeed, it is possible that the leg work I put into researching this topic during my final year of college will have been the difference maker. At that point, I will speak to my superiors about acquiring an extra seat on the next mission to Mars for my former STS professor (and it won't cost $50,000).

Conclusion

Mankind should focus on developing a hydroponic agricultural solution in order to sustain human life on Mars. There are many benefits to exploring the Red Planet, but when it comes to sustaining human life throughout the required 3-year roundtrip voyage, there is only one that truly matters – survival. The principal benefit of both food production alternatives is clear, so determining the best food production method will be primarily based on mitigating risk. Using Lambert's HHM model offered a way to examine the various complications that may arise when relying on either the PPM or hydroponic method in space. The next step will be to invoke a formal, trained team of analysts to investigate the drawbacks of both food production alternatives. People with relevant experience–whether it be botanists, NASA employees, or astronauts–must be consulted to ensure the determined risks and criteria are truly relevant to the agents of the system.

While conducting analysis on complicated systems to be used in outer space and other planets may seem far-fetched, mankind will not be a single-planetary species forever. In fact, we are very likely to see a human being step foot on another planet within our lifetime. While some claim that this dramatic step forward will occur out of necessity as Earth becomes uninhabitable due to environmental damage, I do not think this is the primary motivation behind a mission to Mars. Instead, I believe it is mankind's inextinguishable penchant for exploration that will ultimately propel us beyond the boundaries of our own world. Humans have pushed the limits of what is possible for thousands of years, thus accelerating the progress of our species far beyond any other. This will continue for thousands of years to come, and arriving on Mars will be only the beginning.

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