Hydroponic Crop Cultivation (HCC) for Food Security in Small Island Developing States
(Technical Report)

Mission to Mars: Sustaining Human Life Through Food
(STS Topic)

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Introduction

Hurricane Dorian was one of the most devastating natural disasters to ever come out of the Atlantic Ocean. The Category 5 storm touched down in the Bahamas on September 1st of this year and ravaged the island for two days. While the shocking death toll and damage estimate numbers were heavily publicized, a much less touted fact was that 60,000 people on the island were in need of immediate food relief (Beaumont, 2019). Organizations like the World Food Programme attempted to help by airdropping 14,700 individual meals-ready-to-eat (MREs), but this was merely a temporary solution to the serious problem that both food stores and the little usable crop land had been largely wiped out (World Food Programme, 2019).

Food security is one of the toughest issues to solve within a community attempting to recover from a natural disaster. Small Island Developing States (SIDS) – characterized by small size, isolation, and susceptibility to natural disasters – face a particularly unique challenge in securing enough food for their citizens following a traumatic event like Hurricane Dorian. Many SIDS are overly dependent on food imports, with some countries importing almost 95% of their food and beverages (Food and Agriculture Organization of the United Nations, 2019). This can create a host of problems for these nations such as poor nutrition and the underdevelopment of rural areas. A potential solution to this problem could be found in hydroponics, which refers to the growing of plants in a nutrient-rich solution without the need for soil.

Our team will build off the work of previous capstone groups to design a prototype hydroponic farm that can withstand the environmental challenges of significant rain and wind. The hydroponic unit will provide both supplemental fresh food during disaster relief and a potential livelihood through selling high-value crops to the tourism industry. The technical portion of my research will focus on the specific dimensions, functionality, and implementation of the prototype hydroponic farm. I will also examine the different methods used to sustain human life on a journey to Mars using an STS approach.

Hydroponic Crop Cultivation in Small Island Developing States

The idea of supplementing or even replacing traditional agriculture methods with hydroponics is not new. There currently exists a wide variety of successful hydroponic systems, from small research units to massive commercial farms. An example of the former can be found in the Mars Lunar Greenhouse (MLGH). 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). Large-scale hydroponic farms have proven to be commercially valuable, such as Go Green Agriculture, a company that has used its hydroponically-grown lettuce to secure contracts with retail giants like Costco and received honors at the White House from President Obama (GoGreen Agriculture, 2019).

Our group proposes to solve the specific problems of SIDS by developing small, individual hydroponic farm units capable of enduring the unique challenges presented by the remote island environment. Between 1998 and 2017, the 10 countries most severely affected by climate-related disasters in terms of percentage of their gross domestic product were all small Caribbean states (United Nations, 2018). Considering the frequency with which typical SIDS experience natural disasters, the system must be capable of surviving significant rain and wind while still remaining functional. It is unrealistic to expect any hydroponic unit to survive a Category 5 storm like Hurricane Dorian, but the unit should be able to withstand tropical depressions and storms. Our group is specifically concerned with mitigating the adverse effects of wind damage and flooding. Therefore, the hydroponic system must withstand winds as fast as 73 mph and rainfall up to several inches (National Hurricane Center, 2019a).

In order for the farm to resist damage from high winds, our group is considering several different design options. When selecting a protective shielding for the product, choosing a shape that minimizes the angle between the wind direction and the shield surface is critical. The simplest way to do this would be to use a semi-sphere covering that encloses the entire structure, thus preventing wind from acting directly perpendicular to the cover regardless of its direction. However, the construction of this semi-sphere would be complex and expensive. Another option would be to use a hip roof that extends to below the hydroponic trays and is anchored to the ground. The hip roof was found to effectively alleviate wind shear in the New Jersey Institute of Technology's study on home and roof shapes that best resist hurricanes (2007).

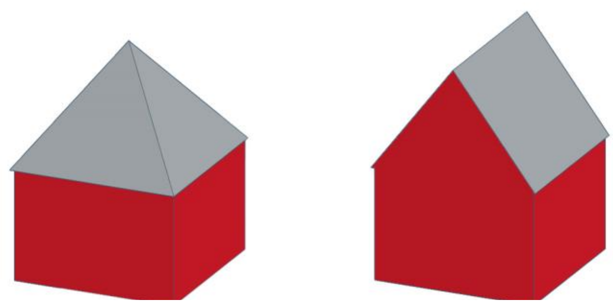

Figure 1. Hip vs. Gable roof (Pro-Tech Roofing, 2019)

The hydroponic unit must resist not only wind damage but also the negative effects of flooding. Seawater seeping into the hydronic solution exposes plants to excessive salinity levels and can hamper plant growth (Klados & Tzortzakis, 2014). Also, particularly strong storm surges can raise the water level up to 20 feet and are more than capable of sweeping away plants and destroying a hydroponic unit (National Hurricane Center, 2019b). A floating hydroponic farm could solve these problems associated with flooding by riding on top of the increased water level, thus not allowing salt to come into contact with the plants and resisting the destructive wave action of the flood. Floating hydroponic farms were experimented with in Bangladesh in 2011 as an effort to help the very poor and landless regain their livelihoods after a devastating flood season. The experiment had mixed results – while 177 out of 200 participants managed to grow crops using their farms, 77% of them made no effort to protect their platforms and thus received less than optimal yields (Irfanullah et al., 2011).

Testing would be needed to find the best means of anchoring the floating platform while meeting the needs of the SIDS communities. One design option involves staging the hydroponic farms in whatever spot on the island the farmer deems suitable, and then tethering the farm into the ground at that location. Using a weighted anchor is too cumbersome and expensive, so the tether would be attached to the ground utilizing a method similar to screwing an umbrella into the beach. A rope would connect the farm to the screwed-in tether, allowing the unit to rise with the water level during a flood. As far as material, a dense foam called polystyrene is both cheap and known to work for floating docks (Universal Construction Foam, 2019). The final product would be a hydroponic farm secured to the top of a polystyrene base platform, with the base connected to the ground using the aforementioned tether and rope system.

Combining both wind and flood resistance into a single hydroponic unit is difficult, but the benefits would be worth it. Hydroponics is much more efficient than traditional agriculture in terms of crop yield. A study in Yuma, Arizona found that hydroponically-grown head lettuce produced a crop yield roughly 11 times greater than that of lettuce grown through conventional agricultural methods. This is even more impressive when you consider that the hydroponic method used 13 times less water and 10 times less land (Barbosa et al., 2015). This final benefit is especially important considering that there is very little arable land on remote SIDS – barely over 1% of the land in the Bahamas is suitable for agriculture while 37% of the land in the rest of the world is arable (The World Bank, 2016). During times of disaster relief, hydroponics could serve as a valuable source of supplemental food until foreign aid can arrive to the island.

The advantages of hydroponics are not limited to the more efficient use of resources or relief in times of natural disaster. Hydroponics is also a potential means through which SIDS could gradually transition to producing their own food. Agricultural independence is associated with many economic and environmental benefits such as lower food prices and increased genetic diversity of crops (Brain, 2012). Our capstone team plans to provide a hydroponics introduction course to the SIDS community along with the physical farm unit. This will give the island residents the background knowledge they need to develop more comprehensive hydroponic systems tailored to their unique needs. The hope is that as time goes on and hydroponics is gradually accepted into the SIDS culture, communities will rely less on foreign food imports as their hydroponic production increases. While there are certainly many STS benefits involved in designing a storm proof hydroponic unit for SIDS, the following section will consider a different problem – how to produce adequate food to sustain human life on Mars.

Producing Food on a Voyage to Mars

While my technical project will investigate an individual hydroponic farm solution to the unique problems posed by SIDS, here I will discuss the challenge of providing food for humans voyaging to Mars. Specifically, 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 as an STS issue through the SCOT lens.

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. While this may not seem overly complicated at first glance, many physiological and psychological considerations must be taken into account when creating a menu for the astronauts. 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). Another concern deals with food quality. 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 a substantial change in 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).

Framing this problem within the SCOT theory reveals how the unique physiological and psychological needs of humans in outer space are shaping the technologies involved in feeding astronauts. There are many different stakeholders in the situation including NASA, private space agencies like SpaceX, future generations, and the astronauts themselves. Because astronauts need to preserve their mental health during the highly strenuous deep-space mission to Mars, 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). Therefore, the NASA team works hard to prevent menu fatigue by crafting a menu of over 200 carefully engineered food options (NASA, 2019). The food has also been frontloaded with nutrients using 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.

Using hydroponic greenhouses to grow fresh vegetables and fruits offers a more sustainable but complicated means of feeding future Mars explorers. One promising prototype is the aforementioned Mars Lunar Greenhouse, which could serve as bioregenerative life support system to keep astronauts alive on Mars. There are many obvious benefits to this system such as efficient use of resources and sustainable food production. A hydroponic system would take up less space than a missions-worth of pre-packaged meals for an entire crew, and would likely be cheaper in the long-run as well. Another 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.

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 (berries, beans, and other antioxidant-rich foods) (Heiney, 2019). 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 from Earth or growing food on Mars? This question is of 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 pre-packaged meals or experimenting with new methods of hydroponic crop cultivation. To answer this question, I will collect mainly secondary evidence on the topic such as prior literature, agency reports, think tank reports, and online resources. As for primary evidence, I will try to organize an interview with someone on the staff of the Smithsonian National Air and Space Museum in Washington, D.C. However, I am 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 has been collected, I will analyze it using the case comparisons method. Essentially all space expeditions up to this point can be considered case studies for the pre-packaged meals method. I found a number of experiments during my research that involved humans living solely off of bioregenerative systems for a period of time – I will use these trials, combined with existing supplemental research on hydroponic systems, to make up the case studies for growing crops in space and on Mars. The two different 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 plan to come up with a set of concrete criteria that I can use to assess the value of each option. Some examples of what these criteria might consist of include daily caloric output, mass, energy requirements and savings, cost, and appeal to the human crew. Each factor will likely be measured using an ordinal data scale of 1 through 5. I will take special care to ensure that the criteria 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 they should be judged and evaluated in a similar manner. After scores have been determined for each factor in both methods, an overall score will be calculated and a conditional recommendation with trade-offs will be made.

Conclusion

Food security is one of the biggest obstacles currently standing in the way of an exploration mission to Mars. As the climate continues to grow warmer and the human population grows exponentially on Earth, creeping ever closer to the planet's carrying capacity, it is imperative that we investigate other potential worlds for human habitation. Therefore, space agencies should take immediate action to solve the Mars mission food problem and directing significant resources towards a potential solution – but which solution should they choose, pre-packaged meals or growing their own crops in space?

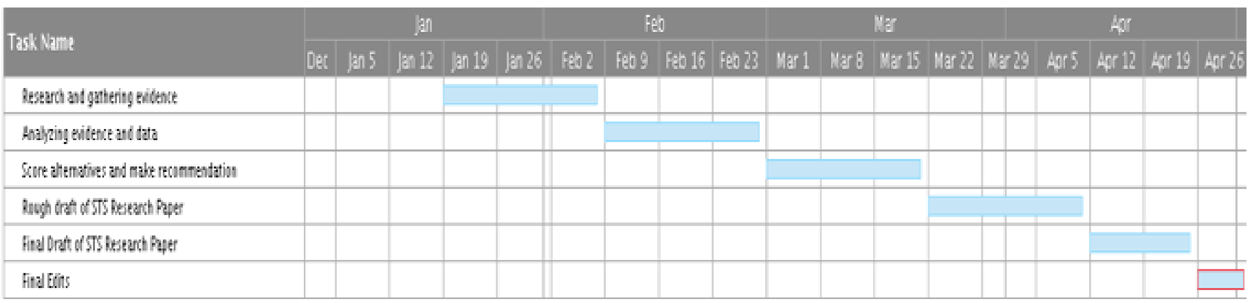

Figure 2. Gantt chart of planned deliverables

I plan to create a scoring system that ranks both food production methods from 1 to 5 in a series of specific criteria. This deliverable aims to bring clarity to the complicated situation of sustaining human life for years at a time away from the comfort of Earth and its familiar resources. The Gannt chart above outlines how I will produce this product in terms of exact tasks and dates. While answering the question of how to feed Mars voyagers will require an immense amount of research from professionals more experienced than myself, this problem will ultimately require the attention of not just astronauts and engineers but all of mankind.

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