Communications: a Literature Review for Future Communications Mitigations

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Abstract

There are many concerns with humans living and working in space. These are only compounded by the length of time and distance from Earth that the humans are travelling. For NASA to figure out countermeasures to these problems, they need to be looked at from different directions from a variety of domains. Psychological concerns will be one of the determining factors to whether or not humans will be able to successfully make a journey to Mars or beyond. Communications will be one of the pivotal factors that will affect a crew from a psychological standpoint. During this summer internship, this intern was tasked with looking into delving into this problem. The intern was tasked with performing a literature review on the topic of comparing communications from how they are conducted now to how they will be carried out in the future. These communications have many methods and functions for when and where they happen. A matrix was created to illustrate how these specific communications methods and functions currently are and could be carried out in the future from a time/location perspective. This research will used to help determine what future research will need to focus on in a psychological and technological aspect to better help the crew of a long duration mission.

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List of Acronyms

A

AC	Asynchronous/Co-located
ANSIBLE	A Network of Social Interactions for Bi-lateral Life Environments
AR	Asynchronous/Remote

D

DRATS	Desert Research and Technology Studies
DSH	Deep Space Habitat

E

EVA	Extravehicular Activities

F

FD	Flight Director

H

HERA	Human Exploration Research Analog

I

ISS	International Space Station

J

JSC	NASA's Johnson Space Center

L

LDEM	Long-Duration Exploration Mission
LEO	low-Earth Orbit

M

MCC	Mission Control Center
MMSEV	Multi-Mission Space Exploration Vehicle
MTS	Multi-team System

N

NEEMO	NASA Extreme Environment Mission Operations

O

OWLT	One-Way Light Travel

S

SC	Synchronous/Co-located
SLSSI	Space Life Sciences Summer Institute
SR	Synchronous/Remote

Introduction

The following report will cover the internship that was completed as part of the International Space University class of 2015 Module 5. The internship was performed at NASA's Johnson Space Center (JSC) in Houston, Texas during the time frame of June 1 to August 28, 2015. This internship was hosted by Wyle Science, Technology and Engineering Group (Wyle), which is one of the leading employment contractors at JSC, specifically in life sciences realm. NASA was brought into existence by President Dwight Eisenhower as a direct response to the Soviet Union's launching of Sputnik. The National Advisory Committee for Aeronautics was absorbed into the forming of NASA and from that time on NASA has been the driver of the America's space program. JSC is the hub of NASA's human spaceflight program and has hosted the training and most of the research done regarding human spaceflight. Many famous events that have taken place in NASA's history has had the JSC as the catalyst, from Alan Shepard's first flight, the first steps on the moon, every space shuttle launch and the creation of the largest international endeavor done by humankind, the International Space Station. During the summer at JSC, there were two aspects of the internship that were participated in throughout the summer. One aspect of the internship was that of the Space Life Sciences Summer Institute (SLSSI) and the other was a research project that was performed within NASA's Human Research Program (HRP).

The first part of the internship was a classroom component called the SLSSI and this program is directed by Lauren Merkle, Ed.D. The SLSSI program is an initiative under the Human Health & Performance Directorate and that has the goal of introducing students to a broad scope of biomedical topics that have to do with supporting NASA's mission of space exploration, specifically human spaceflight. The program entailed many multi-faceted lectures from astronauts, researchers, and administrators all with the goal of giving a broad overview of how each of their domains interact with and affect various aspects of human spaceflight. Some of the topics covered were on astronaut selection, bone health, cardiovascular physiology, toxicology, immunology, exercise countermeasures, human factors, analogs, space medicine, and space radiation. There were also multiple tours of JSC locations to provide the students a complementary perspective to the lectures on how the work being carried out by the students affected the broader scope of NASA's space exploration mission. This included but was not limited to tours in the Food Lab, the Virtual Reality Lab, Anthropometry & Biomechanics Facility, Neurosciences Lab, and the Space Vehicle Mock-up Facility.

One of the many other divisions located at JSC is the Human Research Program (HRP), which is tasked with finding the best methods and technologies to aid in the pursuit of safe and efficient human spaceflight. HRP is divided into 6 different elements that focus on different aspects to complete this goal: International Space Station Medical Project, Space Radiation, Human Health Countermeasures, Exploration Medical Capability, Behavioral Health and Performance, and Space Human Factors and Habitability. The Behavioral Health and Performance (BHP) Research

Element is further divided into 3 research areas: Behavioral Medicine Risk, Team Risk, and Sleep Risk. Complementary to BHP Research is the Operational Psychology group, which deals with all the operational aspects of psychological health of the astronauts and their families. The project topic was posed by one of the members of the Operational Psychology team, psychologist Al Holland, PhD, who was fundamental in the creation of the BHP Element. The prompt from Dr. Holland was posed as an interest in communications and how they would be handled in future exploration missions such as a trip to Mars. The research and written aspects of the internship were focused on the research side of BHP and was mainly supervised by Lauren Blackwell Landon, PhD of the Team Risk area with additional support from Jason Schneiderman, PhD and Brandon Vessey, PhD.

This report will outline the internship and the project as assigned. It will also cover some events that occurred throughout the summer that had significant effects upon the completion of the project. This will include addressing the author's role in the completion of the overall scope of the project and where it stands at the end of the time frame of the internship. This will be followed up with a reflection on professional and personal gains throughout and recommendations to future students.

The Internship

Familiarization with Topic

Contact with the BHP Element was made a few weeks before arriving at JSC. A conference call was conducted where introductions were made and the topic was introduced by a number of the researchers involved in the basics of the project and some details were discussed on the manner of the direction for the project. The description of the topic was somewhat similar to an issue that was of great concern and warranted many hours of discussion earlier in the school year for the Interstellar Worldship team project. This was a complementary starting point to have a conceptual idea of what a project on this topic would entail, in regards to complications with communications. Whereas the team project focused more on a cultural and ethical level problem of communications, the internship project itself would be focused on a much smaller close-knit team setting of communication, the crew of an expedition mission communicating with the Mission Control Center (MCC), as opposed to a population of a colony ship communicating with the entirety of Earth. A few documents were presented to the author about the division and the element that were reviewed for an overview of how the project would fit into the greater scope of human exploration. A preliminary research study performed recently was also passed on and reviewed before the start of the internship. This gave the author an adequate background on the idea of the topic from a research perspective and was used to help shape the direction that would be taken with the author's own research performed for the internship.

Once the author arrived onsite at JSC and performed all the necessary administrative functions required for the internship, he was turned over to the SLSSI Director. From that point appropriate accommodations were made with a desk and IT features. The author then made it a point to reach out to the most available BHP team member, Deputy Element Scientist and Sleep Risk scientist Sandra Whitmire, PhD, who was very welcoming to questions about all manner of topics that would essentially be covered by BHP but were not specifically her area of expertise. However, she did provide the author with many answers, as well as initial directions of where to go to find the information that provided more adequate bits of information. She provided the author with the HRP 2014 Fiscal Year Annual Report, which would in turn give the author a more detailed scope of what type of work HRP was currently working on, recently completed, and had slated to continue with in the upcoming year. Some of these research topics had to deal with various aspects of communications. Along with that report there were also a number of links provided that took the author to the Human Research Roadmap, which led to the Evidence Book. The Human Research Roadmap is a database detailing all of the current research going on in the HRP, across all 6 elements. The name of the specific risks, the gaps of knowledge regarding data pertaining to that risk, and the tasks that are in progress to research that specific gap are listed in the Evidence Book. Reviewing this database gave another view at what HRP as an entity was focusing on and how about each gap was being approached. This gave insight into specific research methods being used by various researchers from around the world to look into the identified problems, some of which involved various aspects and concerns for communications. With this information, over the next couple of days, the author proceeded to delve into the Annual Report and the Evidence Book, reading the entirety of the report. When going through the majority of the Evidence Book many questions were brought up and written down to address with someone at a later date and time. These questions were later brought up to many of the author's mentors, Dr. Landon being the main point of contact, during some of the initial meetings. Formal communications were made with the BHP Research Team during the second day during a regularly scheduled team meeting. Many individuals were present and each held different position within the research team and focused on different topics of interest and eventually would become points of contact throughout the internship for information and specific questions regarding the research topic.

Research Discussion

During the first meeting with Dr. Landon, the author possessed a considerable amount of knowledge regarding the background of the HRP and BHP Element. This knowledge however did not encompass the direction or scope of the to-be-assigned project at the time. Introductions were made with Dr. Landon and the other individuals who would be helping focus the direction of the project, Drs. Jason Schneiderman and Brandon Vessey. Dr. Vessey was also looking at the topic from the Team focus with Dr. Landon whereas Dr. Schneiderman was looking at it from the Behavioral Medicine perspective. The project as it was described and understood by the author was to produce a literature review using research from various fields of study regarding communications and to compile it into one single source of data pertaining to the topic of communications during a Long Duration Exploration Mission (LDEM). The concern for such an influential delay has been supported by an initial report, which included interviews from operational staff, stating that they recognize that communications will be a problem for crews in the future of human spaceflight (Flin, 2013). This particular topic is an issue of concern because currently all human spaceflight missions have only ever been performed within low-Earth orbit (LEO), with the exception of the 9 missions to have travelled to the moon, the 6 that landed and the 3 that orbited. Though, the Apollo missions that actually traveled to the moon have technically left LEO, the distances traveled to the moon are minute in comparison to the distance to Mars or beyond. It is due to these distances, and the physics of the electromagnetic spectrum, that One-Way Light Travel (OWLT) to the moon is only approximately 1 second. However, at the same time the OWLT to Mars is on average 22 minutes. For this reason any mission that has not gone beyond the distance will be considered a LEO mission. This distinction is of concern because radio waves travel at the speed of light and because of that the astronauts at the moon were talking with Earth essentially in real-time, while an astronaut on Mars would be speaking with a 22 minute, 1-way delay.

This assignment was at that time understood as searching known databases, for example Google, Google Scholar, ISU Library, SAGE Journals, ResearchGate to look for relevant research. Along with these, a number of individual articles from different researchers and different domains were given to the author to look through, as well. Though it did take a while to get complete working access, the process of getting the author access to the internal NASA databases provided an immense amount of cataloged articles covering many of relevant topics. Of the previous research found, most of it did not directly address the issue of communication delays in regards to human spaceflight and even fewer addressed the topic in relation in an on-Earth context.

Part of this research also included a book entitled *Human-Computer Interaction: Second Edition* (Dix et al., 1998a) that was loaned by Dr. Schneiderman. This book covered a large amount of data but of particular interest was that on the chapters of *Groupware* and *CSCW and Social Issues*. These two chapters would be used to shape the foundation of the project. Groupware is used to define systems that have been designed with collaboration of users, in mind from the beginning (Dix et al., 1998b). This would include anything from a joint workspace to a multi-user word-processing software. In this consideration there are a number of factors and issues that need to be taken into consideration: the location of the users, the relative time to each other when using the resources, and the resources themselves. Each system would be particular to each communication method, time frame, and physical location of the communicators. Not all systems are designed or even capable of being used in every situation. This can be illustrated in Figure *1*.

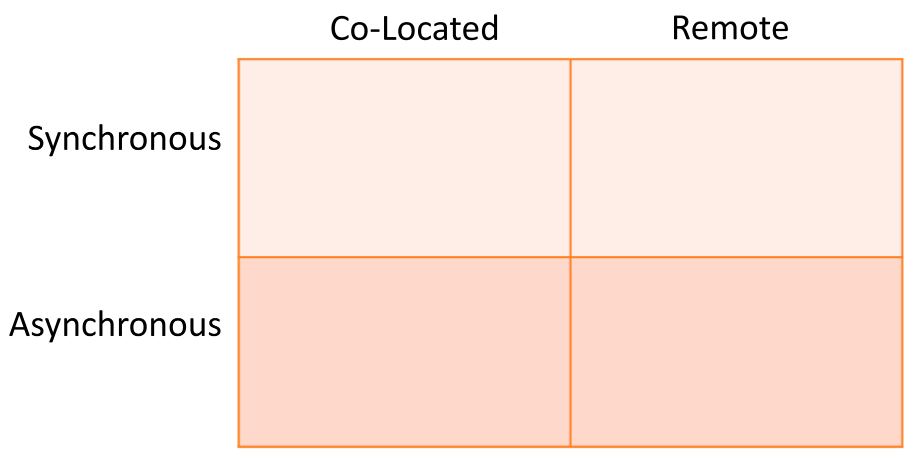

Figure 1. Generic Time/Space Matrix.

The next important chapter that was reviewed covers the topic of computer-support cooperative work. This is focused on the interactions of the individuals with the computer system with which they are working (Dix et al., 1998c). This needs to take into consideration the method of traditional human-human interaction and decide upon the best method for conveying the same aspects of communication through the computer system. That aspect includes analyzing specifics of body position and other factors of communication to make sure they are all properly incorporated into the given system to provide the most conducive communication environments possible. This is where the initial divergence of the project outline occurred for the author.

After spending some time doing more research, reading, and comparing of articles, a better comprehension of the project and its goals were achieved. While attending one of the weekly tag-up meetings with Dr. Landon between Bi-weekly Report 2 and 3 it was discovered that the author and the mentor were looking at the actual content of the deliverable in very different ways. While the initial scope of the project idea was to look more so at the differences between the communications methods in relation to the matrix seen in Figure *1*. The author was actually looking at the scope of it in a slightly different manner, involving taking not just tools for communication and allocating them across the matrix but rather taking the functions for that communication and further subdividing those by the specific methods/forms of communication that would be most suitable and efficient for that reason of communication. This, in turn, presented a larger topic to cover and therefore more consideration needed to be taken in the form setup and explanation of the research and the literature review.

Literature Review

In this section the literature review itself will be discussed. The paper will be outlined in a summary fashion discussing the most relevant aspects of the research. Hands-on aspects of research will be discussed with regard to how these played a role into the final paper.

Research Review

The literature review examines communication concerns between differing groups and functions of communications. The definition of communication for this literature review includes visual, auditory, and text-based transmissions as well as the transmission of raw computational data such as that conveyed between two computers or databases. This review will cover a number of situations and teams for the analysis of communications. This includes transmissions within the crew, within MCC, and communication between the two. Each of these teams are part of a much larger Multi-team System (MTS). However, MCC is its own unique example of a MTS. This required the author to do additional research into multi-team systems and how they behave. This was particularly the case in regards to MCC because of the level of complexity that exist in such a specialized type of MTS. This is the case because there are many specialized teams that focus on the efficiency and maintenance of their own component of a spacecraft or aspect of a mission. At the same time they each need to be extremely cognizant of how their specialty fits into the global picture of the mission. They each have a team lead, the flight controller, who is sitting at the console in MCC directly observing the components of their given system. They are then supported by a team of members who are in a different location but always available, through a variety of means, to aid in the case of a problem arises. A good example of this is during operations on the International Space Station (ISS) or more notably the scene in the movie Apollo 13 where the engineers are trying to figure out how to fix the carbon dioxide scrubber issue on the ground while the crew in space, waited for the solution. The interview of the MCC Flight Director (FD) covered a vast amount of these topics and was an essential component to understanding and properly covering this information in the review.

This concern can be directly applied to the communications between the two teams during a LDEM. This is of concern because due to the time delay between Earth and a mission to Mars or beyond there will always exist a time delay in communication between Earth and the crew. On Mars, this would be a delay on average of 22 minutes in one direction. Therefore, communications that people take for granted on a daily basis in everyday situations and in particular those between mission and the crew of a spacecraft will be greatly affected. As such, each will need to be considered and mitigated in its own way.

Initially, the project proposed was something that resembled a matrix such as in Figure *1*. Therefore, research across many databases in various fields of study was reviewed and collected to compile this information. The research concluded that there is a time/space matrix that can be used to illustrate aspects of communication. This matrix is broken into relative time of communication and relative location of the communicators. This is further broken into two divisions of each. Time is divided into Synchronous vs. Asynchronous, or real-time vs. delayed-time. Location is divided into Co-located vs. Remote, or being in the same physical location vs. not being in the same location. Due to this distinction a matrix is created with time context rows of Synchronous and Asynchronous and location context columns of Co-located and Remote. When put into the grid this would result in four distinct types of communication: Synchronous/Co-located (SC), Synchronous/Remote (SR), Asynchronous/Co-located (AC), and Asynchronous/Remote (AR). SC Communications would be that of a "regular" conversation with two or more individuals being in the same location, such as in a meeting, speaking to each other in real-time, with a "no lag" call and response setting. SR Communications would be a conversation that would be had in a real-time environment but where the two or more parties are not physically present in the same location; a simple example of this would be a telephone call or a videoconference. An example of AC would be something similar to a note, reminder, or message board. It is accessed in the same spatial location but at different periods. AR is a conversation transmission that occurs in different locations at different times such as a voicemail or an email. Once the grids of the matrix had been decided upon what information to use to fill them. There were a number of discussions had with the mentor and it was decided that the methods of communication would be used in each of the four grids but then the possible tools would be listed alongside them. This does two things, first it makes the matrix much cleaner as well as primes the reader to be able to self-identify the criteria for each domain in the matrix.

In each of the four grids of the matrix there are three methods of communication that were most heavily identified in the research, that would be video, audio, and text. A fourth method of communication, being data, was identified during an interview with a MCC FD and therefore subsequently added to the matrix outline. They are each unique and described as such. Video is where you can see the individual(s) with which you are having the conversation. Audio is the fact that you can hear the individual(s) with which you are having the conversation. Text is where you are writing to the individual(s) with which you are having the conversation. Data is identified as communication between two computers or databases and not requiring any human input besides their initial setup and/or connections. Otherwise, it is something that is taken care of independently of human interaction. Though, after a while the decision was made to change the terminology of video to visual, audio to auditory, and text to text-based/textual. The author made the changes because it allowed the terms to better incorporate situations and scenarios across the entire matrix as opposed to being situated for just one particular grid of the matrix. The final product resembled the matrix shown in Figure *2*.

	Co-Located	Remote
Synchronous	**Joint Meeting Space** Video – In-person, face-to-face Audio – direct communication Text – Notes, collaboration software, Ouija Board Data – logs, database	**Separated Joint Work** Video – Skype, WebEx Audio – Telephone, conference call, radio, yelling Text – SMS, email, chat software, collaboration software Data – logs, database
Asynchronous	**Different Times** Video – Video messages Audio – Voicemail-type messages Text – notes, reminders, message board, lists, notices Data – logs, databases	**Time Delayed Operations** Video – Video messages, procedure walkthroughs, ANSIBLE Audio – Voicemail-type Messages Text – Emails, message boards, short messages Data – logs and database in data chunks

Figure 2. Completed Matrix.

The corresponding part of the review came in the form of another matrix, which will be referred to as the sub-matrix. This is what the author was considering as the project when it was discovered to be a different scope from what the mentors were envisioning. When compared to the other matrix, this sub-matrix actually existed as an expanded and further detailed component of each of the grids from the matrix. The sub-matrix was created to look at the different functions for communication between a crew and ground control and plotting that against the methods for communication. This means any purpose that the crew or ground would have to initiate contact with each other. This would include things such as Psychological Support, Family Time, EVA (Extravehicular Activity), Emergencies, or even Operations. Each of these functions denote a different level of importance associated with them depending on which part of the MTS is being considered. Therefore, each reason has different constraints and requirements to what is the best method for achieving each of their goals. These have been identified per reason on a scale of High/Medium/Low Effectiveness. This scale is a determination of the most viable method of communication determined by the author’s research, observations, and interviews.

For example in the case of an EVA only some of the methods of communication are currently used for an EVA on the ISS. For instance, the visual method, or video in this case, is only directed one way, from the spacesuit to MCC so that MCC can observe what is going on during the EVA in real-time. This is also the case for the auditory method, MCC has the ability to speak to the EVA crewmembers and they can respond back in a real-time conversation. It was due to these 2 methods that MCC was able to recognize and act upon the water leak in Luca Parmitano's spacesuit during ISS Expedition 36/37. Currently, there is not a form of text-based communication between the EVA crewmember and MCC so that is not something that is factored into the methods of communication. However, all communications that do happen currently fall into the SR grid because of the real-time access but distant physical location of both communicators. However, when you consider a Mars mission, you have a number of complications that arise, which also present with a number of grid references for communications. Referring to the protocol in Figure 3, developed by the NEEMO (NASA Extreme Environment Mission Operations) and DRATS (Desert Research and Technology Studies) team, there are a number of "loops" of communication ideally that would be utilized.

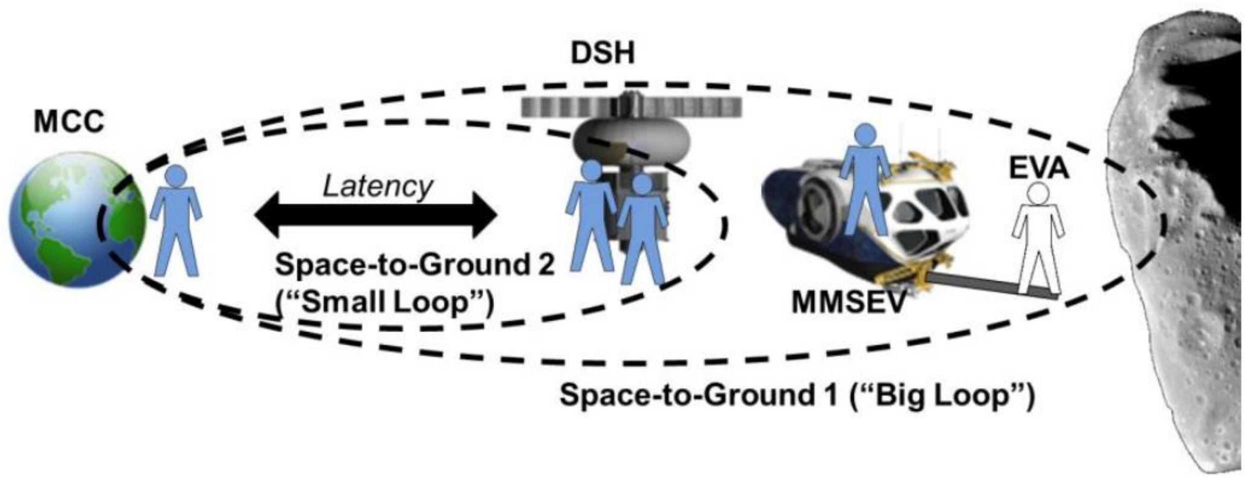

Figure 3. EVA Communications Loop (Abercromby et al., 2013).

As can be seen in the figure there is a "Big Loop" and a "Small Loop". The Big Loop comprises of all communications that Earth would be aware of from the DSH (Deep Space Habitat) and the EVA team, which includes the MMSEV (Multi-Mission Space Exploration Vehicle). Though MCC is aware of all transmissions made by the crew, they will always be behind what is currently happening during the EVA and in the instance of another water leak, a 22 minute delay could definitely be fatal. This type of situation would be amongst the AR grid of the matrix. Therefore, what would happen is MCC would communicate the entire procedure of the EVA on the Small Loop to the DSH through the AR grid. At that point the DSH will become a local mission control and therefore, DSH and EVA will be able to communicate on a "Smaller Loop" in a SR capacity and communicating in the same manner that MCC currently speaks to ISS (Abercromby et al., 2013). At the same time the MMSEV and EVA teams could fit into either SC or SR depending on what characteristics are viewed as more pertinent to the allocation. Therefore, in regards to the sub-matrix EVA would have a video rating of High, because it would be the same as it is now for current ISS EVAs. However, auditory would have a rating of High because the ability of the two parties to speak to each other can be done in real-time between EVA and DSH allowing for quick assessments of problems and procedures. Unless the dexterity of the spacesuit gloves improve significantly by the time of the LDEMs then hand dexterity will be at a diminished level. Hence, text-based communication would not be of use for the EVA crew and therefore would receive a rating of Low. However, currently data is relayed between the suits and MCC and so this could be continued with the EVA and DSH teams, which of course will all be picked up by Earth mission control, just not in real-time so technical and biometric data will still be of importance and receives a rating of Medium. These points are illustrated in Figure 6.

Another example is in the case of Family Time there are many variables. Currently, the crew has scheduled videoconferences scheduled videoconferences with their family, once a week. This is established and done over a video connection so the crew and video connection so the crew and their family members can see and hear each other in what is essentially real-time, negating essentially real-time, negating the millisecond delays due to the logistical aspects of communicating with the ground from communicating with the ground from anywhere in orbit around Earth, as seen in Figure 4

Figure *4*. They also have the ability to use the IP Phone that is on the ISS to call down to their family essentially whenever they want to, schedule permitting. This affords them the ability to speak over the phone with their family outside of their scheduled videoconferences. This type of activity would fit into the SR grid due to the distance in location of the 2 communicators.

Figure 4. Current Family Communications (NASA, 2014).

However, when it comes to a delay of a Mars mission length the ability to have a real-time videoconference or to pick up the IP Phone and dial home whenever they want will just not exist, the known laws of physics would not allow it. This type of situation would firmly put this type of communication in the AR grid of the matrix. Therefore measures would need to be put into place that would allow communication with their loved ones. An example of such would be a virtual reality system, such as ANSIBLE (A Network of Social Interactions for Bi-lateral Life Environments) developed by SIFT and funded by a grant from NASA. This system would allow an individual, be that crew or family, to enter the system and create a familiar world. It would function a bit similar to some current mainstream video games except its purpose would be entirely different. It would allow the individuals to recreate a meaningful environment, such as a house and/or neighborhood, as seen in Figure 5.

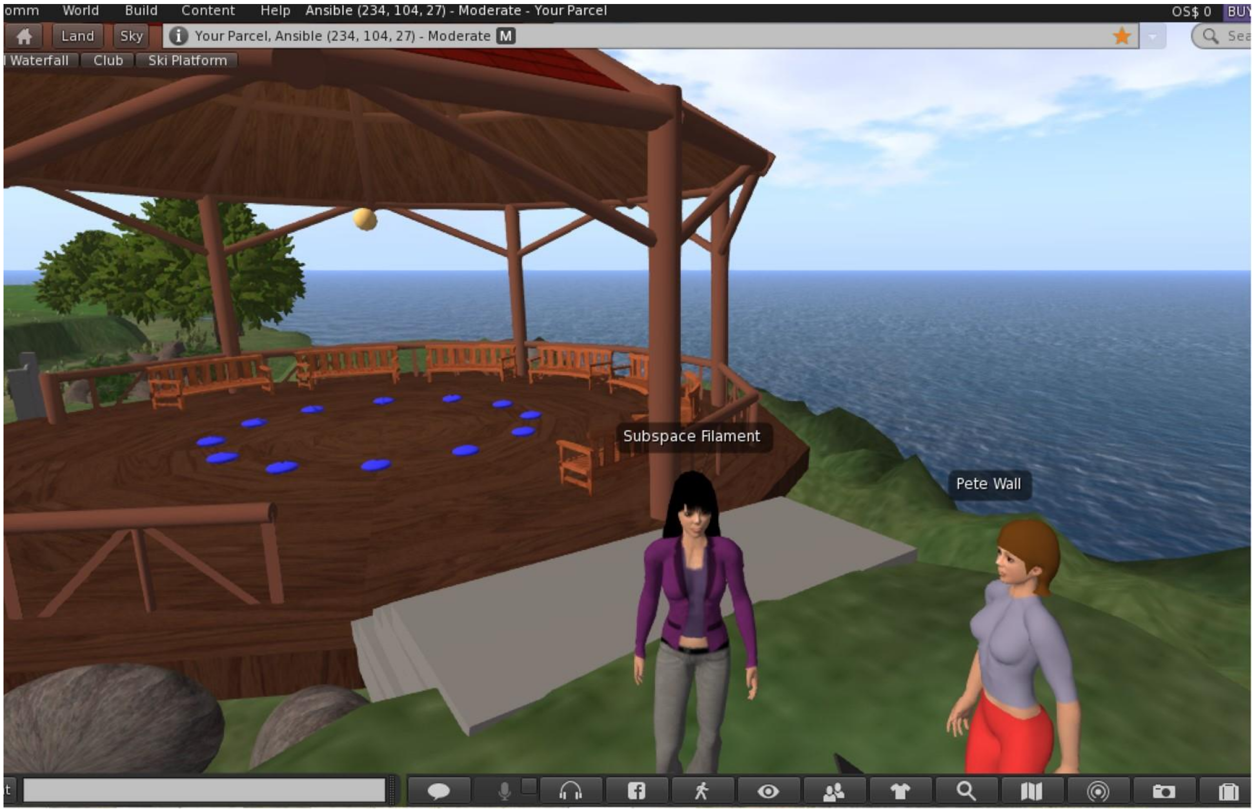

Figure 5. ANSIBLE (Wu, 2015).

In this instance, it would present something for the crew with which to ground themselves emotionally. Each member of the family would be able to record a video or audio message, take a picture, or anything of the sort and upload it into the system. That way the other would be able to access it during the next data transmission between ground and ship. This would allow the crew and family members to still have a sense of connectedness with each other without the actual ability to communicate directly to each other. Of course, this would have its own set of problems: the amount of data needing to be transferred and the still existent time delay but it would be better than absence of communication entirely. Particularly, since one of its more valuable features would be to allow the visual information between crew and family, they would still be able to see each other, even if they cannot have the real-time functionality of a SC conversation. Therefore, considering this information the Family Time Category would receive a rating of High on the visual scale because of the importance seeing your loved ones. It would then receive Medium on the auditory scale because it would be the next most valuable method of communication. While at the same time the text-based scale would receive a Medium rating as well because of the ability to still “hear” from the loved one regardless and there are many instances of many people who currently communicate in this manner in modern times over email, SMS, and instant messenger systems. Of course, it is not the best means but it is better than the absence of communication. In the instance of Family Time data would receive a low rating because although getting biometric data on the crew member or getting report cards or work evaluations of the spouse it is information but not enough. It is a very passive method of staying abreast of what is happening with the loved one and so does not hold as much weight for a desired method of communication. These points can be found illustrated in Figure 6.

	Psych	Family	EVA	Ops	Status	Emergencies
Video	H	H	H	L	M	M
Audio	M	M	H	M	M	H
Text	L	M	L	L	M	L
Data	L	L	M	H	L	M

Legend: H – High Effectiveness. M – Medium Effectiveness, L – Low Effectiveness

Figure 6. Sub-Matrix.

Another example of a communication reason would be that of the Psychological Support that the crew would receive while on a LDEM. There were not too many articles covering the topic of psychological support in a delayed setting. There is some current work that is being done on electronic therapy sessions handled by a phone app but this are only being tested for clinically established patients that have had many sessions with their therapist prior to being put on this type of system, one example of such is being done with diagnosed alcoholism (Gustafson et al., 2014). Though, much research has not been done in the field it is fortunate that at the time that the author was researching the field two NASA grants were awarded to a researcher at UCLA and Stony Brook colleges to study just this fact of what is the best method of psychological support done in a non-face-to-face method. The research is set to discover which is best whether that be in a visual, auditory, or text-based method. Due to there not being an abundant amount of research in this field the rating system used for this communication reason was based on some previously known knowledge from the author's personal educational background, as well anecdotal accounts picked up from conversations with other researchers.

As can be seen in the sub-matrix, there are a number of communication functions that have been highlighted and their individual communication methods examined. These functions were the ones that were noticed to be mentioned or performed the most throughout the research. The author used best judgment, taking into consideration the research performed, when it came to creating the hierarchy for the effectiveness scale making note to take into consideration the way the communication is currently being carried out and then how it would be used in a near-future situation. This is taking into account current and up-coming technologies not anything that is not currently in the works of being created. The grid of the matrix that was expanded here for illustration is that of the AR Grid. However, each of the communication functions and their corresponding methods fall into at least one of the four grids with the simplest coming under the SC Grid while the more technology focused coming under the AR Grid. Each grid could possess two matrices, one from the viewpoint of each communicator. It was realized that this was not only a possibility but almost necessary depending on which aspect of each form of communication was being discussed. Many of the components on the grid could, and most likely will change, depending on who the initiator and receiver of the given transmission is.

In conclusion, it was discovered that there are many functions for communications with just as many tools depending on where the communication falls on the Time/Space Matrix. Though there may be many possibilities there is has not been a definitive perfect answer as to what is the best method of communication for a given communication reason. That would all depend where on the matrix the communicators fall, whether that be SC, SR, AC, or AR. Each method of visual, auditory, text-based, and data communication can be used for each but they each have their own effectiveness levels depending on what the reason for the communication and who is the initiator of the transmission. There are many aspects that still need to be looked into to get a better grasp of the topic at hand. The project of the literature review is the beginning of a larger research focus looking at a very important aspect to the future of human space exploration. There are three pivotal factors to humans successfully carrying out a LDEM and those are the duration of the mission, the physical space provided to the crew, and the communications delay between crew and ground support. Therefore, this is an important issue to be considered for future spaceflight. Further research should be focused on a more in-depth look at each of the methods and functions to more definitively expand on what has already been studied. It has been suggested that more points of interest be added to the topic such as at what time delay increment do each of the communication functions begin to present with detriments. Another future interest is to look at localizing as many of the communications as possible, such as with a virtual reality system to limit logistical constraints of constant communication between crew and Earth. At the time of this report the author is working on finalizing the literature review and therefore more recommendations for the future and insights on the literature may come to light. The final information will better inform researchers on understanding the problems of what effects communication delays have on individuals work performance and psychological well-being. It will also shed light on the issue of countermeasures for said individuals, as well as other operational concerns that will have to be taken into account for such an operationally specific circumstance such as time delays. One of these many issues are the amount of bandwidth that is transmittable at any given time and the allocation for what will get priority throughout the mission.

Practical Research

During the internship the author had the opportunity to participate in a number of hands-on opportunities that were applicable to the research done for the literature review. This made a number of the research topics a bit more salient had applicability to the research that was being done for the final product of the paper. Together with the paper they each played a role on furthering the insight of the project and demonstrating where and how it fit into the overall picture of the HRP.

HERA

Figure 7. HERA analog (NASA, 2015).

As part of the research performed for the literature review, the opportunity to actually observe some of the research as it was being carried out. This offered a great opportunity because many of the space analogs that NASA uses for research implement a time delay in communication between the analog crew and the analog mission control. These observations conducted during two analog missions, which occurred at the beginning and end of the internship. The analog observed at JSC is entitled Human Exploration Research Analog (HERA), seen in Figure 7. HERA is operated as part of NASA's Flight Analogs Project, which is the division focused on operating high-fidelity analogs that can be used for studying different conditions of the spaceflight environment. There are typically 4 individuals, per mission, and each of these individuals have education and experience similar to those would be classified as "astronaut stereotype". Previous HERA missions have been operated for a period of 7 days and future plans are to operate missions for as long as 60 days. Two HERA missions occurred during the summer, Campaign 2 Mission 3 and Mission 4. During these HERA missions the crews were "sealed" in the habitat for a period of 14 days. During their isolation, on days 5 and 6 of the mission there existed a 5 minute communication delay with mission control and on days 7 and 8 there was 10 minute delay. The author had the opportunity to sit with mission control and observe the daily activities of the crew and to see how they interacted with each other and with mission control throughout their meticulously scheduled days. This was a good experience because it gave the opportunity to observe the interactions between the crew and their mission control during a communication delay. It was seen how the crew and mission control interacted with each other when there were large amounts of time between them recognizing a situation and responding and the other team actually receiving that message and being able to act accordingly. An example of this is the emergency simulations that took place on various days throughout the mission. The crew would simulate an accident and then attempt communication with mission control and wait for a response. All the while the crew is assessing the injured crewmember and looking for the best method of treatment. This would all occur before mission control would be alerted to the problem, due to the time delay. Then mission control would have to respond with appropriate instructions, depending on the injury, and then would have to wait for the crew to receive them and respond back accordingly with either updated information or the results of the instructions that were passed on to them. This timeline is illustrated in Figure *8*.

Timeline (24-hr)	Events
1500	Crew Member #1 injures arm
1501	Crew Member #2 begins care
1503	Crew Member #3 messages MCC
1505	Crew Member #2 splints arm
1510	Crew Member #4 administers medication
1513	MCC receives message
1515	Crew Member #1 is stabilized
1520	MCC responds with info

Figure 8. Delayed Communication Timeline.

A few points were noticed during interactions such as these. First, the two teams (crew and missions control) appeared to use audio communications for the most pertinent information that needed to be relayed between the two of them. Second, quick responses to instructions, an utterance of “okay”, “we’ll work on that”, or “give us a few minutes” were mostly all conveyed over a text-based system that was available to all members of the mission. These perceived actions are part of a protocol that the crew and mission control were trained. The protocol has specific guidelines on how to carry out a auditory communication, utilizing call signs, topic cues, body of content, and a signoff (Fischer and Moiser, 2015). The protocol was developed by a research Ute Fischer to eliminate communication strains, such as the one experienced in a communication delay. From the observations it appeared to not be followed 100% of the time but when it was it was instrumental in clearing up any possible confusion that may have occurred due to the flow of the conversation. The protocol has been implemented in many other analogs, included a few NEEMO missions and previous HERA missions. Having the ability to observe the protocol in pace during active operations provided the author with a more salient understanding of the research being done to produce and utilize countermeasures that would need to be in place to ensure efficient communications in an asynchronous working environment.

SCUBA

Another hands-on experience that had applications to the problem of communications, how to define them, and where they fit on the matrices, was SCUBA Diving. The author had the opportunity to become certified in SCUBA by JSC’s Neutral Buoyancy Lab divers. Due to the author’s previous experience with diving many of the skills were quite familiar and so observing the other students actions and interactions became the focus of each of the dives. Before each dive there was a meeting with all the fellow divers on the surface of the water, this is similar to a briefing that would be given before any EVA done by a crewmember in-orbit. This type of meeting of course fit into the SC grid because all individuals were in the same physical location and were able to speak and respond as necessary. However, once everyone finished donning their equipment and dove under the surface, it was quite different from an EVA. For instance, the individuals still on the surface or not in the water at all, lost all communications with those under the water until they resurfaced, clearly putting any communication between those two groups in the AC and AR grid. However, even for the individuals that traveled under the surface together this was still different from the conditions of an EVA. First, there were no auditory communications, in the way of spoken speech, nor were there any video capabilities. This greatly limited the scope of what type of excursion was feasible. Without the ability for basic SC or SR communications a coordinated dive became very difficult, if not impossible, unless meticulously trained for before diving. Despite that, without communications there is no way to guarantee that level of precision in the activity. Second, visibility was another issue that was of great concern. Many times the visibility was not much better than arm's length and so giving or receiving visual cues from another person was very difficult, as well. At one point on a dive the author decided to start teaching another diver basic American Sign Language, which is a form of communication that uses visual gestures and signs to convey an idea. This allowed the two to establish a better position of communication otherwise without such a method the interactions would have just consisted of a small number of mutually understand gestures and anything else would have to be conveyed once both individuals returned to the surface. Therefore, two or more individuals occupying the exact same space within arm's length of each other were delegated to operating in the AC grid because of the necessity of delaying communication until a later time. This experience with diving put the problems with communication, even when someone is right next to you, more in perspective than can be conveyed on paper. This is a very applicable scenario to crew during an EVA because if communication, be that auditory or visual, is lost between them there needs to be an established set of guidelines and procedures on how to operate despite that loss. It would be prudent to look into establishing a back-up system of communication, or specifically in the case of future spacesuits that offer a bit more dexterity in the hands, an alternate form of communicating with another member of the team.

Interviews

When it comes to other hands-on opportunities the author was able to experience this came in the form of interviews. One of the people that the author had the opportunity to interview was a JSC FD. This was such a great opportunity because it allowed the author to compare what had been researched in regards to multi-team systems to an operational environment. Reading about how MCC operated proved not as tangible as being able to actually sit and speak with one of the FDs directly, and hear what they had to say about their job and how all of the intricacies affected everything else to make the job as difficult and rewarding as it appears to be. Through one of the other interns present on campus during the summer the author was made aware of the availability of one of the FDs and proceeded to reach out to said FD and was allowed to set up a meeting time to conduct an interview. The author, with the help of Dr. Landon, prepared questions for the FD that would look at different aspects of the project, concerns of multi-team systems, current communication issues, and future aspects to consider. During the interview topics such as the FD's background were discussed. This was of particular importance due to this individual's specific background. While serving in the position of flight controller, this individual was instrumental in mitigating a very important problem, with little to no time or resources to fix the issue. This specific problem played into the ability of communications to be readily available and used an aspect of every grid of the matrix. This scenario occurred at the lower-level of the MTS but as the individual took on the role of FD they operated in a different level of the MTS. Not only are they the ultimate decision-maker in the JSC MCC, they are also the top decision-maker for operations from all over the world that impact the ISS, its crew, and its mission. This role places the FD at the top the combined MTS trees of other mission control centers from around the world, each possessing their own communication constraints and intricacies. All of these control centers incorporate the entire matrix in multiple. When talking from one control center to another, this method of communication occupies the SR but when the individual FDs at each center are speaking with their flight controllers that is SC and when controllers communicate with their support teams it is a combination of grids. Then all the data for the entire mission is always being logged in one database or another and that fits the role of AR. When asked, during the interview, regarding the idea of possible communication problems in the future an interesting idea was proposed. The crew could assign or have tasked a proxy on Earth, someone with whom they trust and are able to make final decisions and then pass them onto the crewmember. This is similar to the Big Loop/Small Loop system in Figure 3 but reversed. This could help alleviate a lot of the problems of communication delay due to fixing the problem, on Earth, with the intrinsic knowledge of the crewmember and then sending the results in one transmission. This would eliminate the need, unless absolutely necessary, for back-and-forth communication and therefore eliminating the large amount of time between problems and their resolutions. It is an interesting idea, perhaps one beyond the scope of the literature review, but one that may be worth looking into at a later date. Throughout the interview a lot of information was learned on the method by which MCC operates and provided an insight to a MTS that the author had never had considered before the start of the project.

Another interview the author was able to conduct was with psychologist Al Holland, who was the lead individual for creating the BHP Element, and also the individual who proposed the initial idea for the project being undertaken. Dr. Holland stated that he approved of the information and the work that the author had performed and presented to the BHP Element team, as well as previously to the group of interns as part of SLSSI. Many of the points that were discussed with Dr. Holland have been incorporated in other portions of the research and writing. He is also very interested in using the work as a starting point to performing a more in-depth analysis furthering the research done. Many characteristics regarding the communication delays were discussed aiding many of the outcomes and future research directions of the literature review. Avenues for how to proceed with studying the factors that would lead to these concerns being figured out were discussed in-depth. He also mentioned the relatability of some of his other work to that of working with the astronauts. In 2010, the 33 Chilean Miners that were trapped in a collapsed mine were one of the examples that were brought up. It was discussed how similar and not similar their situation was to what a crew on a LDEM would experience. Some of the measures discussed that were used for the miners are some of the same considerations that could be used as countermeasures for some of the concerns discussed in the literature review.

Benefits

Gains

I would have to say that there were many benefits from participating in an internship opportunity such as this. First off, this was my first internship experience that I've ever had the opportunity to undertake and so it was a very eye-opening experience to an unfamiliar work environment. At this point in my life I have worked in one capacity or another for over half my lifetime but it had always been in the corporate world or for myself. Having the ability to intern at NASA, specifically at JSC, has given me the chance to experience things that I would have otherwise never had the chance to do. I have been able to sit in on meetings about important future work. I have been able to participate and observe in real empirical research, firsthand. I have been able to sit in on lectures being offered by the researchers in the field who walked directly out of their labs to talk to myself and others on topics ranging from neurosciences to immunology to spacesuit design. I have made contacts with individuals from all corners of research during my time at JSC. Participating in this internship has also solidified my interest in what I want to pursue for a doctoral program. From speaking with many of the researchers here about research that is ongoing or that they had participated in I was able to better develop my field of interest and create a more concrete idea of what, academically, I would like to pursue in the future. NASA was not my initial interest for locations of internship, I was actually looking at other country's space agencies but when it came down to it NASA was the best choice of places for me to go to support my interest of human spaceflight. I was able to fully apply all manner of knowledge learned from the MSS program, whether that be from classes, discussions with professors, or assignments. I was able to adequately apply my knowledge from the MSS program to what I was experiencing and learning through the internship at NASA. I fully received everything from the internship that I was expecting: an opportunity to work inside the space field with industry experts, the opportunity to see and experience things that I never had the chance to before, ability to apply my knowledge to learn and better understand things to which I was exposed, and the chance to learn whatever I wanted.

Recommendations

I, first and foremost would, suggest to anyone that they have an idea of a field in which they want to intern. It does not have to be something entirely specific, such as adolescent neuroplasticity.

However, they should have a general idea of wanting to work in a specific field as this will help them narrow down the locations at which to look for internships. Once they know where it is they want to gain experience they should start looking and applying to those companies or organizations that do what they want to do because the internship opportunities will fill up very quickly. Even if it is a golden opportunity, wherever that individual decides to go make sure that they have the means to support themselves for the amount of time they plan on going. Having to worry about housing, food, and transportation throughout one's internship is definitely not the most helpful activity. Make sure, within reason, to stay in constant touch with your mentor onsite. They should be the one to help you the most throughout your internship and will make the entire process so much smoother than not having their help. Befriend anyone and everyone that can be befriended. There is never an opportunity where you should shy away from talking to someone new or someone that may just not seem approachable. If the opportunity is there to speak with that individual, then do just that. You will never know who will be the person to help you out on your research, on finding a job, or perhaps on a special tour that is not normally given. During the internship is not the time to continue or start being shy. The students are there to learn and all employees know it and they will go out of their way to help impart whatever knowledge you are willing to learn. If you do not understand something then make sure you ask questions about it. Regardless of what it is, you are there to learn in a field that may or may not be familiar to you but you can be sure that the individuals you are working with are very knowledgeable about it, make sure you use that. Last, but not least, make sure you go to where you feel you want to go. Do not feel that you are forced to take an internship that may not be best for you. I was given the opportunity at two different locations but I decided to choose JSC. I may very well have had the opportunity to meet some very prominent and influential people at the other opportunity but what I wanted to do was get in the research in the field that I cared about and so I did just that and came out of it with a great experience, future research ideas, contacts, and friends that I know I will keep.

Conclusions

The internship report presented aspects of the internship that played a significant role in carrying out the project that was assigned to the author. The amount and methods of research carried out for the literature review was constant throughout the internship time period. The coverage of the topic was well received when presented to a general group of individuals, as well as the subject matter experts. Analysis of the research presents with many different avenues of communications that are present in a multi-team system such as the human spaceflight program. There are two main factors of communication when it comes to group work and that is time and space. These time and space factors can be further broken down in a matrix into their corresponding grid of conditions. Each one of these conditions of communication presents with its own set of tools to perform that communication. The research then shows that each grid possesses a set of methods for each communication function identified. These methods are visual, auditory, text-based, or data. Depending on what the function of the transmission was that would determine what the most likely and effective method of communication should be in that corresponding grid of communications conditions. These findings will aid in directing future focus of study that will be influential in the future of human spaceflight to destinations of Mars and beyond. Many benefits were gained from this experience and can and will be carried forward into future life and career endeavors.

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