Early Assessments of Crew Timelines for the Lunar Surface Habitat

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As NASA progresses towards sustained crewed space missions, crew timelines will become increasingly important to achieving mission goals. While it is desirable to spend as much time as possible during crewed space missions on science activities and experiments, there are a large number of activities that crew members must perform each day in order to maintain both crew and vehicle health and safety. The time available for science activities in space is highly dependent on mandatory tasks required for crew and vehicle health and safety. The different crewed activities need to be planned accordingly long before the start of a mission in order to optimize crew time for science. To begin assessing the potential crew time for available for science, an understanding of the requirements to maintain crew and vehicle health and safety is needed. These additional activities may include sleep, exercise, vehicle maintenance, logistics handling, crew personal time, as well as many other tasks. The remaining time outside of these required tasks, within a reasonable crew work schedule, can be dedicated to science operations. This paper will detail a collaborative effort to analyzing crew times for sustained spaceflight missions and how the results of that analysis are applied to the crew timeline for the proposed Lunar Surface Habitat (SH).

To determine the crew time for all of these required activities, an analysis was conducted utilizing defined agency requirements and historical crewed mission data. Predicted crew activity times were integrated into a daily schedule in order to optimize the crew's time during the mission. This methodology was utilized to produce expected crew timelines for NASA's proposed Artemis Base Camp (ABC) missions. The current plans for the ABC contain two different sustained habitats, the Pressurized Rover (PR) and the Surface Habitat (SH). While the crew are separated between the two habitats, the timelines for each element are dependent on the other element's operations, so the two element timelines are formed in conjunction with one another. The results described in this paper, however, will focus solely on the crew timeline in the SH. This paper will explain the methodology behind predicting the required crew time spent in the SH for each activity, and the process of incorporating these predicted crew times into a coherent schedule.

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I. Introduction

NASA's Artemis campaign is unique in many aspects. The campaign will include a sustained human presence on the Lunar surface, with missions beginning within the current decade. When the Artemis Basecamp (ABC) is fully operational, it will include four crew members spending 28 days on the Lunar surface, living in two habitable elements, a Pressurized Rover (PR) and the Surface Habitat (SH). While the ABC missions are very different from previous NASA missions, there are still historical resources that can be utilized to prepare for planning a 28-day surface mission [1].

When assessing crew time requirements during space flight missions, it is important to designate the tasks that must be completed during the mission. Researchers designated a crew time activity ontology, described in Table 1, to categorize every possible crew activity [2].

Table 1 Crew Activity Ontology

Category	Sub-Category	Major Activity
Work	*Scheduled Operations*	Vehicle Ops
		Upkeep Ops
		Outfitting
		Medical
		EVA
		Logistics
		Training
		Exercise
		Utilization
	Ops Prep and Conference	Work Prep
		Public Relations
		Conference
		Tag-Ups
Non-Work		Personal
		Sleep
		Meal

Categorizing the crew activity aids analysts in planning missions earlier when mission details may still not be finalized. For example, while an analyst may be unaware of specific filters that need changing 10 years prior to the mission, historical data may show to expect at least one hour dedicated to changing filters during the early part of the mission duration.

The crew time ontology separates the crew activities into two major categories: work and non-work. Non-work categories are dedicated to crew personal activities and include sleep, meals, pre and post sleep activities. It is important to note however that these activities, while personal time, are still planned and scheduled. There is additional unplanned personal time that must be accounted for in operations planning, and that will be discussed later. The second category, work, can be further sub-categorized into Scheduled Operations and Ops Prep and Conferences (OPC). OPC activities can be described simply as "indirect work" and involve conferences with the ground control, ground and/or flight crew tag-ups, public relations activities, and work preparations for the day. The Scheduled Operations activity all include "direct work," and these activities include in vehicle or upkeep or outfitting operations, medical activities, Extravehicular Activities (EVAs), logistics stowage or trash removal, training activities, exercising, followed by utilization and science operations. This paper will include a larger focus on planning for the scheduled operations, as these activities are the most sensitive when looking to optimize the crew schedule for both crew health and mission objectives. However, historical data aids analysts into a good first estimate of required crew time for future missions through the continuous missions on board the ISS.

After over 20 years of continuously crewed missions, crew activities onboard the International Space Station (ISS) have become precisely defined. These requirements are centered around crew and vehicle health and safety, but, similar to jobs on the Earth's surface, often include restrictions on workload and personal time requirements. The crew activity guidelines are detailed in the ISS's Safety Requirement Document Space Station Program (SSP) 50621-01 [3] and provide insight into the general time distribution for the ISS crew members. The document outlines requirements and guidelines for crew sleep, personal time, conferences, public affairs, and daily workload requirements on top of every other defined crew activity, excluding corrective maintenance. Table 2 below provides a standard ISS weekday for a crew member.

Table 2 ISS Guidelines for Standard Crew Workday

Crew Off Duty (13 hrs)	Sleep Period	8.5 hrs	
	Post Sleep Period	1.5 hrs	Includes a morning meal
	Midday Meal	1.0 hrs	
	Pre-Sleep Period	2.0 hrs	Includes an evening meal
Crew On Duty (8.5 hrs)	Operations	6.5 hrs	This time is used to calculate crew time at the tactical planning level.
	Operations Prep/Conferences per Section E.1.4	2.0 hrs	Daily Planning Conferences: ~15 minutes each duty day morning and evening.
			Work Preparation & Plan Familiarization: ~50 minutes for daily plan familiarization, report preparation, and evening prep work. ~20 minutes for morning prep work.
			Conferences per Table E.7-1, On Duty Crew Conferences
	Task List		As time becomes available (at the real time planning level)
Exercise (2.5 hrs)		2.5 hrs	Includes time for setup, cardiovascular/resistive exercise, stowage, and hygiene [cool down plus cleanup]. This is not operations.

This standard ISS day closely resembles what will be attempted on the Lunar surface in the SH, and ISS ontology closely reflects the ontology established in previous crew time assessments [1]. However, there is a sharp contrast between standard ISS missions and the proposed Lunar surface missions for specific, lower-level activities. Additionally, the ISS guidelines are general rules of thumb for crew time allocations. Actual crew time distributions at the task level on ISS vary from day to day and mission to mission.

Analysts completed assessment of actual ISS crew time distributions based on data from NASA's Operations Planning and Timeline Integration System (OPTimIS). OPTimIS captures crew time data from each crew member, every day. Analysts utilized a data processor to categorize the OPTimIS data into the ontology described above, allowing for a comparison of actual crew time of activities compared to ISS guidelines. Additionally, OPTimIS provides additional crew time data on activities that may not have predefined guidelines, and this data can be used in assessing future crew timelines during Lunar surface missions.

This paper will detail the iterative process of establishing early crew timelines, followed by subject matter expert inputs, and finally forming the schedule to a point that it is accepted by all individual mission operations stakeholders, from crew health and safety and EVA experts to maintenance and supportability experts while still maintaining the goals and objectives for the mission. To begin, the process of predicting expected crew times for each activity will be outlined prior to bringing all of the activities together for a cohesive crew timeline.

II. Crew Time Activity Assessment

Non-Work Activities

Non-work activities describe scheduled personal time for crew members during the mission. These activities include sleep, pre and post sleep, and mealtimes. When predicting expected times for these activities, ISS guidelines and historical data is the best source of data. Due to the high-cost and shortened duration design of the Lunar surface missions, as compared to the ISS missions, scheduled personal time may be decreased to maximize crew working hours. Each of these activities will be described individually along with the process of predicting an expected crew time.

Sleep

Sleep is a unique activity compared to the others as requirement are relatively invariable, with solid defined requirements. The daily per crew guideline for sleep is 8.5 hours a day, and the OPTimIS data shows that this guideline is largely followed. When planning a 28-day Lunar surface mission, it is assumed that each crew member will retain the daily 8.5 hours of sleep.

Post-Sleep

Post-sleep activities are morning activities following the crew waking up. They typically encompass breakfast and using the bathroom, and then any remaining personal activity as decided by the crew member. This could include, but isn't limited to, reading, writing, morning movies, or any other personal activity. ISS guidelines allot 1.5 hours per crew member daily (10.5 hours per week) for post-sleep activities. While this allocation can be supported by crew during a 28-day lunar surface mission, the possibility of crew requiring more time of the day dedicated to work activities must be considered. To prepare for this, the timeline analysts looked to crew health and flight operation subject matter experts for further details on this crew activity. Following expert input, the assumed post-sleep activities allocation could be reduced to 1.0 hours, if necessary, while still allowing time for meals, bathroom visits, and any additional stretching or morning activities to prepare the crew for the day.

Pre-Sleep

Pre-sleep activities are personal activities for crew members to prepare for sleep. Similar to post-sleep activities, these include meals, bathroom usage, and any other activity the crew considers vital to prepare them for sleep. Post-sleep activities could also be reduced from the guideline suggested 1.5 hours down to 1.0 hours. However, because pre-sleep personal activities are conducted in preparation for sleep, decreasing these personal activities from the schedule may affect or decrease crew sleep, which is to be avoided if possible. Because of this, early Lunar SH crew timelines hold a firm 2-hour time for pre-sleep activities.

Meal

Meals outside the pre-sleep and post-sleep meals are mid-day meals. On ISS, the guideline for midday meals are 1.0 hours per crew member daily. The historical ISS data on meals reflects the crew often utilizes the full hour for meals. For SH missions, it assumed that these mealtimes can be decreased due to time constraints and the more defined meal plan. For Intravehicular Activity (IVA) only workdays during the SH mission, 30 minutes for each crew member is allotted for midday meals. For EVA workdays, the midday meal schedule is planned differently. The SH crew conduct 8 8-hour EVAs over the mission duration, and these EVAs will likely take place when a midday meal should be scheduled. Instead of attempting to schedule a meal before or after these long EVAs, it is assumed crew will eat during the EVA. While this meal will be scheduled into the crew's EVA plan, it will not be scheduled into the crew's mission timeline. However, the SH concept of operations (ConOps) still includes off-duty days in which the crew will schedule a full midday meal of 1 hour per crew member.

Work Activities

Work activities include all activities required to maintain crew health and spacecraft health and to achieve mission objectives. The total duration of these activities that are not related to utilization have a direct effect on the crew time available for utilization operations. If these non-utilization work activities are not properly accounted for and planned, there can be gaps in the time planned for utilization activities, potentially impacting objective satisfaction . While these activities are planned around ensuring crew and vehicle health and safety, the goal is to optimize these tasks to allow for the most amount of utilization time possible. Crew time estimates for work activities are estimated from guidelines and historical crew time data.

Ops Prep and Conferences

The OPC activities are based around ground and flight team communication. For tag-ups between crew members onboard the ISS, the goal is to increase team communication and be sure the team activities and goals are in-line with what is being perceived on the ground.

Work Prep

According to the guidelines listed in Table 2, ISS plans 70 minutes total for plan familiarization, report planning, evening work prep, and morning work prep. As the Lunar SH mission is 28 days flown one year apart each, the amount of preparation and plan familiarization before the mission allows for a reduced requirement of the activities for the Lunar SH mission. Examining the OPTimIS data results, the historical ISS average for Work Prep activities is roughly 4 hours a week per crew member. Lunar SH analysts consider this time to be more reasonable for a Lunar SH mission, and currently expect 30 minutes daily per crew member for work preparation; 15 minutes for morning prep work and evening prep work each.

Public Relations

Public relation activities for space flight missions are a crucial element of these missions. Being a government agency, NASA relies on public interest in their affairs in order to ensure funding for each cycle. While it takes crew away from other utilization activities, being engaged in public affairs during the Lunar mission is an important aspect of the Artemis campaign. Historically, crew members average around 1.25 hours onboard the ISS weekly on public affair activities. When looking at a complete Lunar SH crew timeline, 30 minutes per crew member weekly during off days will meet the baseline for keeping the public engaged in the mission, while not overworking the crew or cutting into important utilization operations. While increased public relations activities would support public engagement, it is likely that either automated or ground controlled efforts would be made to support these activities as to not burden the crew in the SH.

Conferences/Tag-Ups

Conferences onboard the ISS are meticulously planned, and their cadence and requirements are precisely defined based on the mission and crew members on board. Table 3 from SSP 50621-01 [3], shown below, details the conference schedule for ISS crew members.

Table 3 ISS Conference Guidelines

Title	Frequency	Crew Time	Total
DPC	15 min/twice daily	0:30 x 6 crew	900 min/week
FD Conference	20 min/weekly	0:20 x 6 crew	120 min/week
ГОГУ Conference	15 min/weekly	0:15 x 6 crew	90 min/week
PMC	15 min/weekly	0:15 x 6 crew	90 min/week
CB Crew Conference	15 min/every 2 weeks	0:15 x 6 crew	90 min/every other week
PPC	15 min/every 2 weeks	0:15 x 6 crew	90 min/every other week
Program Mgmt Conference	20 min/quarterly	0:20 x 6 crew	120 min/quarterly
SSIPC Crew Conference	20 min/weekly when JAXA crewmember is onboard	0:20 x 1 crew	20 min/week
SSIPC Management Conference	20 min/monthly when JAXA crewmember is onboard	0:20 x 1 crew	20 min/monthly
ESA Crew Conference	20 min/weekly when ESA crewmember is onboard	0:20 x 1 crew	20 min/week
ESA Management Conference	20 min/monthly when ESA crewmember is onboard	0:20 x 1 crew	20 min/monthly
CSA Crew Conference	20 min/weekly when CSA crewmember is onboard	0:20 x 1 crew	20 min/week
Pluto Conference	15min/as requested	0.15 x 1 crew	Not to exceed 1.5 hours per increment pair
ISS Crew Tag-ups 9per Section E.3.3.2, Operational Expedition Crew to Expedition Crew Tag-ups)	30 min/twice an increment	0:30 x 3 crew	90 min/twice per increment
PFC **15 min/weekly**	15 min/weekly	0:15 x 6 crew	90 min/week

Table 3 details the advanced level planning and coordination that is required to run the ISS with so many international partners. However, for the Lunar SH missions, a far more basic conference schedule can be utilized. With only two crew onboard and shorter missions, conferences can be more direct and less frequent. When both crew are American astronauts, international conference can also be removed. A Daily Planning Conference (DPC) can be conducted twice a day for 15 minutes. If the crew workload is too strenuous on a certain day, the discussion items of one of these conferences can easily be pushed into the next day's conference. The crew is also scheduled for a Weekly Planning Conference (WPC), which occurs on off-duty days and is planned for 30 minutes. The Lunar SH crew will also use the ISS's Personal Family conference (PFC) schedule, planning for one PFC per week. However, recent ontology updates have included PFC to be personal crew time, not work. Because of this, the Lunar SH crew is allowed a full hour per crew for PFC. Any additional tag-ups the crew may require during the mission can be done during work preparation time, although Lunar SH analysts expect crew tag-ups during the SH mission to be few.

Scheduled Operations

The remaining crew time activities fall under Scheduled Operations. These activities are largely mission based, stemming from mission goals and objectives as well as system architecture. Each activity is analyzed and assessed based on mission ConOps and system requirements, and when each is fleshed out, the leftover time for utilization can be planned. Some activities are defined from the ConOps. For example, the Lunar SH mission will include 8 8-hour EVAs over the 28-day duration, with ingress and egress from a Suitport-Airlock. Prep, ingress and egress times are well defined for these activities.

Other activities, however, are systems based and include a large amount of stochasticity. Expected crew time on maintenance during the Lunar SH mission is driven by random failures in equipment and requires a detailed analysis in order to not only predict distributions for expected crew time, but also to inform the risks associated with planning and accommodating expected maintenance activities. The results of planning each of these scheduled operations will create a time remaining for utilization, and increasing this time is the goal in optimizing the other activities.

Prior to detailing the data analysis and crew time assessment for the scheduled operations activities, additional sub-categorization of the category was performed to ensure the required tasks for the Lunar SH mission were being included specifically. Table 4 below details the additional categorization of scheduled operation activities.

Table 4 Crew Activity Ontology of Scheduled Operations

Category	Sub-Category	Activity	Sub-Activity	Operation Type
Work	Scheduled Operations	Vehicle Ops	Standup/Closeout	
			Traffic	Docking/Undocking
				Berthing/Unberthing
				Vehicle Relocation
		Upkeep Ops	Routine Ops	
			Maintenance	Corrective Repair
				Scheduled Preventive
		Outfitting		
		Medical		
		EVA		Pre- EVA
				Spacewalk
				Post- EVA
		Logistics	Vehicle Loading/Unloading	
			Routine Logistics Ops	
		Training		
		Exercise		
		Utilization		

The first listed activity in Table 4 is “Vehicle Operations.” This activity encompasses any activity of orbiting vehicles such as docking or berthing. Because we are only examining the Lunar SH, already in its final position on the Lunar surface, this activity will be ignored in Lunar SH operations planning. Following Vehicle Operations, we have Upkeep Operations. This is broken down into to sub-activities: Routine Operations and Maintenance.

Routine Operations comprise of housekeeping activities, such as sweeping, checking sensors or monitors, dusting down systems, and similar activities. Maintenance is divided once more into two operation types: corrective repair and scheduled/preventive maintenance. Scheduled/preventive (“preventive” moving forward) is defined as a preplanned maintenance activity dedicated to system health and upkeep prior to a system or component failure. This includes, but is not limited to, filter changes or cleaning, sensor replacements, tank draining, component cleanings, and more. It should be noted that there is a common overlap of routine operations and preventive maintenance. Often, a crew member could be conducting routine operations of dusting a system, and in doing so, clean a specific component that is known to require preventive maintenance. This overlap is known to maintenance and repair crew time experts and analysts, and how this is planned and accounted for will be discussed later.

Corrective repairs are defined as unexpected or unplanned crew time dedicated to a random failure of a component, Orbital Replacement Unit (ORU), or system. Corrective repair activities are difficult to account for, as failures on board the SH are virtually impossible to precisely predict. However, analysts have developed model-based approaches to address the uncertainty surrounding planning for corrective repairs, and the methodology and results of this approach will be discussed further in this paper.

Outfitting

Outfitting, for this assessment, includes any operations that involve bringing dormant or new systems online within or exterior to the SH. The current system architecture for the Lunar SH includes a full closed-loop regenerative Environment Control and Life Support System (ECLSS) on top of the required communications, data-handling, and power systems that support the habitat. Upon arrival to the SH, the crew is required to inspect all of the systems on-board the SH and activate any system in dormancy or reconfigure systems for crewed operations. While the communications, data, and power systems are operational prior to the crew’s arrival, the ECLSS will likely be in dormancy. Heeding advice from ECLSS subject experts, a 1-hour timeslot for both crew members is allotted to complete outfitting tasks when first arriving with the SH. Additional systems and work areas also need preparation, including the medical bay, crew quarters, utilization stations, and more. These systems and work areas are currently planned to be set up during the 1 hour allotted for outfitting.

Medical

Medical operations include regular health conferences with the ground crew, in which medical test results are shared with the ground. Scheduled medical operations come in the form of Personal Medical Conferences (PMC). These involve crew members completing medical tests and inspections on themselves with the results being communicated to ground operations. During the first week following the initial SH ingress, each crew member must conduct a PMC daily. Following the first week, a PMC must be conducted every 5 days or prior to and following an EVA. While crew health and safety subject experts prefer conducting PMCs directly before conducting pre-EVA operations and again immediately following post-EVA activities, crew workload restrictions often hinder this ability. Because of this, crew health subject experts have approved allowing crew to conduct PMCs either the evening before an EVA day or the morning following an EVA day. PMCs are scheduled for 15 minutes for each crew member, and each crew member can conduct a PMC simultaneously as the other crew member or separately.

EVAs

EVA operations consist not only of the EVAs themselves, but any pre and post EVA activity the crew is required to complete. Current Lunar SH ConOps plans for the two SH crew to conduct 8 8-hour EVAs from the SH over the mission duration. While the activities and operations conducted during the EVA will be discussed more with the maintenance and utilization sections, there are required EVA activities not only for crew to ingress and egress to and from the SH, but to ensure crew safety during EVAs. Outside of the required PMCs, the crew must don Liquid Cooling Ventilation Garments (LCVGs) and biomedical monitoring systems before conducting prebreathe operations prior to pre-EVA activities, which according to EVA experts requires 35 minutes total per each crew member. Following these activities, the crew begins the egress operations to leave the SH cabin. Table 5 below lists standard operating times for ingress and egress procedures, based on certain system architectures [5].

Table 5 Estimated Pre and Post EVA Times for System Architectures

Operation	Unit	Airlock with Gas Recovery	Airlock without Gas Recovery	Suitport-Airlock, ingress/egress via Suitport*
Total Prep	min	61	36	24
Total Post	min	79	54	28
TOTAL	**min**	**140**	**90**	**52**

**** Selected architecture for the Lunar SH***

These standard ingress and egress times by system were discussed with EVA and EVA systems experts to enhance the estimate of required EVA ingress and egress times, which were simplified to 30 minutes per crew for ingress and 35 minutes per crew for egress. However, these were not the only system dependent crew time for EVAs. As visible in Figure 1, the SH cabin is situated off the ground. To ascend and descend to the SH cabin, the crew must utilize a safety restraint system to hinder the possibility of crew falling from the SH platform or ladder.

Figure 1 Graphical Representation of the Proposed Lunar SH

While the SH architecture is new to NASA's spaceflight missions, astronauts relying on fall protection of EVA restraints is not, and EVA experts can provide good assumptions on the crew time requirements around these systems. To don the fall protection, ascend or descend the SH ladder, and then doff the fall protection is expected to take 20 minutes for each crew member. For safety, the crew must complete this task individually one after the other. Between doffing the fall protection on the Lunar surface and donning it once more, the crew conducts the scheduled EVA. Once the crew has reentered the SH cabin, they are scheduled to 45 minutes each of post-EVA activities, including equipment doffing, additional dust and regolith cleaning, and stretching among additional activities.

Logistics

Logistics activities in the SH include retrieving the required logistics, stowing them within the SH cabin, upkeeping their organization and tracking the trash throughout the mission before stowing the trash for long-term stowage on the lunar surface. Current ABC ConOps plans are for the PR crew to retrieve the solid goods logistics for the SH from a logistics lander and deliver to the SH's cargo port. This port is located outside the SH's airlock and connects directly into the cabin, allowing the SH crew to retrieve the logistics directly from the Small Pressurized Logistics Carrier (SPLC) that they were delivered in. It is assumed gas and fluids will be transferred to the SH directly via robotic transfer of the PR using an umbilical prior to the crew arrival in the SH. Additionally, it is assumed the crew has enough solid goods in the SH to last the first day the crew arrive. The PR crew will deliver the remaining logistics to the SH the second day the crew is occupying the Habitat. Assuming the SH crew will require 3 SPLCs of consumables and logistics, the current assumption is that opening the hatch for each SPLC, unloading the logistics, then stowing the logistics will take 2 crew members 40 minutes each. Throughout the mission, crew may be required to move logistics within the cabin or repackage trash to take up less volumetric space. While this is logistics dependent, these activities will be categorized and accounted for under Routine Operations. At the end of the mission, the SH crew is required to package their trash into an empty SPLC. Current logistics and trash output models reflect that all the SH trash will be able to fit into 1 SPLC for final stowage on the Lunar Surface. Anticipating that the crew has kept up with the trash throughout the mission, loading the trash into an SPLC ported on the SH's cargo port should only require 10 minutes for each crew member.

Training

Logistics activities involve the gathering, stowing, cleaning, and disposing of all logistics and trash required and compiled during the mission. Training is a unique activity category for this assessment, and it also displays the benefit and importance of beginning mission operations planning early. Because utilization on the lunar Surface mission is still being planned and waiting further timeline assessments, there is a lack of planned training for utilization activities. Additionally, as the systems onboard the SH are still being assessed and decided on, there is a difficulty in planning training for systems and system anomalies or troubleshooting. The current 28-day, 2 crew ABC SH timeline reflects zero training time. Due to the shorter mission duration, it is likely that ABC mission crew will receive more mission-focused training prior to launch and will in turn require less training during the mission. As mission utilization operations develop further, required training operations will develop alongside them.

Exercise

Exercise encompasses the crew's daily exercise requirements, both aerobic and anaerobic activities. Exercise is a vital activity for the crew. When humans are exposed to micro-gravity environments, bone and muscle decay may happen at expediated rates. Because of this, as referenced in Table 2, ISS guidelines require 2.5 hours of exercise for each crew member daily. According to the historical exercise data processed from OPTimIS, the crew is good at keeping up with this requirement, averaging 2.4 hours daily. This exercise guideline is required each day regardless of EVA operations or if it is a day off. However, the environment of the Lunar surface and that of the ISS in orbit is significantly different. While the Lunar surface experiences significantly less gravity than that on Earth – 1/6 of Earth's gravity – the gravity of the Moon provides far more exertion on the human body than that of the microgravity experienced on the ISS. Because of this, Lunar SH timeline analysts examined the basis of the ISS's guideline, and how the exercise requirement could be better suited for the Lunar surface. Through collaboration with ISS crew health experts and the Lunar SH timeline team, each crew member is allotted a reduced exercise requirement of 90 min per day. The 90 minutes consists of both aerobic exercise and resistance training, but due to the SH architecture, only one crew member can exercise at a time. Following the 90-minute exercise decision, the Lunar SH timeline analysis examined an additional interference of exercise on the Lunar Surface – EVAs.

As previously stated, crew on the ISS conduct exercise during EVA days. And while ISS EVAs are long, they are not excessively strenuous. During EVAs on the Lunar surface, the crew will feel the weight of their suits of over 50lbs. Requiring the crew to do this over an 8-hour EVA is significantly more strenuous than ISS EVAs, and this must be accounted for during Lunar SH crew timeline and operations planning. On IVA only days, crew will be required to complete 60 minutes of exercise each. On EVA days however, the crew will complete 30 minutes each of post-EVA exercise. This can be stretching, yoga, or aerobic activity to reduce heart rate. This new requirement also decreases scheduled crew workload on IVA days, resulting in additional time for utilization.

Crew Maintenance

The most uncertain activity when dealing with expected crew time for sustained missions is maintenance and repairs. The large uncertainty in the time spent for repairs is driven by the unpredictability of failures during the mission and the corrective repairs that follow. Corrective maintenance is highly variable based on random failures of components. While average or expected time requirements can be predicted, the actual required time for any given mission will be highly variable based on the actual failures that occur. Additionally, each failure may require a varying degree of time required for repair. In a surface element such as the SH, the large number of unique components contributes to the uncertainty of required crew time spent on maintenance and repairs. The authors have completed an analysis of the maintenance and repair requirements for the current SH mission [4].

Maintenance and repairs are separated into two operations: corrective repairs and preventive maintenance. As described previously, preventive maintenance is scheduled repair to promote vehicle health, and corrective repairs are in response to random failures of components, ORUs, and systems. While both operations are considered systems maintenance to promote vehicle health, they must be analyzed separately. Most components, if applicable, have a defined replace or cleaning preventive maintenance schedule that can be analyzed through historical ISS data. This data can then be directly applied to the same components if they are being used on the ISS. For corrective repairs however, these are driven by random events that can only be modeled probabilistically. Both analyses were completed by NASA Langley senior researchers and engineers along with the Binera engineering and analysis team in 2021 [4].

The results of the maintenance assessment for the Lunar SH were developed through detailed modeling efforts, using data inputs for components, ORU, and systems that will be used on the SH that also include historical ISS data. Repair times, mean time between failures (MTBF), the ratio of repairs to replacements, and additional component Time to Repair data was retrieved from OPTimIS timelines as well as ISS's Maintenance Data Collection (MDC) and ISS's Maintenance and Analysis Data Set (MADS). MDC is a complete failure and maintenance log of all maintenance activity onboard ISS and MADS provides additional component data such as MTBF. Relying on this data and the NASA Langley's Space Mission Analysis Branch's maintenance and crew time model CASSANDRA, maintenance and crew time analysts were able to generate predicted maintenance time for the Lunar SH mission [4].

Beginning with preventive maintenance, the timeline analysis team analyzed defined "life limits" of components on board the SH. The life limit of a component is strictly a defined end of life duration that defines when the part is replaced. By replacing these components before failure occurs, potential failures of other components are deterred by keeping the cohesive system operating at a desirable level. It is often far easier and cheaper to replace parts that are known to increase in failures after a certain operation duration than to wait for random failure. Additionally, analysts examined patterns of cleanings, repairs, troubleshooting or reconfigurations, or replacements of other components that didn't have a life limit defined. By examining these patterns, analysts were able to deduce preventive maintenance patterns and schedules for similar components onboard the Lunar SH. Following this analysis, the analysts were able to deduce a distribution of expected times for preventive maintenance during a Lunar SH mission. Because increased preventive maintenance can reduce required corrective maintenance by a possibly significant amount, analysts agreed to plan for the high estimate, at 22.4 total crew-hours over the 28-day mission.

Planning for corrective maintenance presents a unique challenge. The activity is driven directly by random failures, and because the failures and corresponding crew time for repairs is analyzed probabilistically, the results are not point estimates but rather are probability distributions. Figure 2 below displays the results of the maintenance and repair assessment for the Lunar SH mission [4].

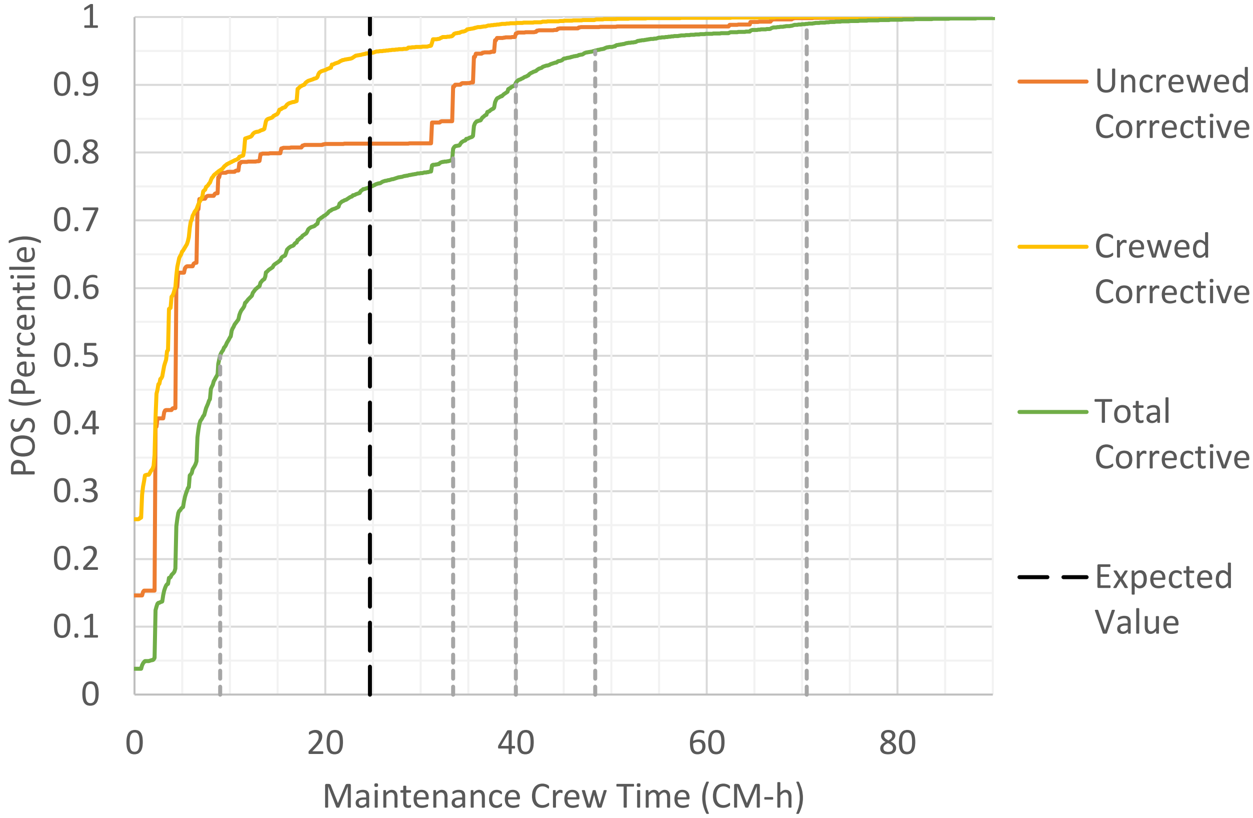

Figure 2 Crew Time Distribution of Corrective Repairs for a Lunar SH Mission

In this plot, the y-axis shows the Probability of Sufficiency (POS), or the percentile, of the corrective repair times. This value shows the probability that the scheduled (plotted) value of crew time on corrective repairs will be sufficient to support the SH mission. For example, the graph shows a planned total corrective repair schedule of 9 hours hits the 50th percentile, meaning there is a roughly 50% chance that the mission will require less than 9 crew hours (CM-h) of corrective maintenance. Additionally, the crew time on corrective repairs is divided between three groups. The “Uncrewed Corrective” distribution describes the required crew time on repairs from failures that occurred during the uncrewed duration of the SH. The “Crewed Corrective” distribution describes the required crew time on corrective repairs from failures that occurred during the crewed duration of the SH mission. The “Total Corrective” is simply the summation of the two corrective distributions. Additionally, the model calculates a mathematical “Expected Value” which is a non-probabilistic expected value utilizing only the MTBF, repair to replace ratio, and repair times [4].

As stated previously, corrective repairs carry the most uncertainty of the crew time activities. With this uncertainty, corrective repairs also have a larger potential variability than the other crew time categories. The variability in expected repair time results in a similar variability in expected available utilization time. If a high number of repair activities are required, then there will be correspondingly less time available for utilization and vice versa. For this reason, corrective repair times and utilization times are often examined together. Because component failures are random and can happen without notice and are also typically necessary to complete in order to continue the mission or keep crew safe and alive, corrective repairs are often conducted in lieu of other scheduled activities. Other activities, such as sleep and eating, are always required for crew safety. So, any variability in repair time directly impacts utilization time.

The distributions of crew time for corrective repairs are highly important when constructing crew timelines. From the distributions, a POS value must be selected in order to plan for an expected amount of crew time. Selecting the POS, whether it be low at 0.50 or the high end at 0.99, implies risk. If more time is available for maintenance and utilization, time is less critical, and a low-risk, high POS value can be selected without a significant impact on utilization opportunities. If time is scarce, a high-risk, low POS may need to be selected to allow for a sufficient time for utilization.

III. Timeline Construction

Following the crew time activity assessment, the Lunar SH timeline analysts began constructing a daily schedule for the SH mission. To begin, the mission ConOps must be defined. The broad view of the Lunar SH mission's daily timeline is shown before in Table 6.

Table 6 Daily Overview of the Lunar SH Mission ConOps

Element	Surface Day	Surface Habitat Event
HLS	1	Landing, Post-Landing Ops
	2	HLS IVA, EVA preparation, HLS surface ops re-configure
SH	3	Egress HLS, LTV Checkout/Reconfigure, Drive to SH/Ingress
	4	EVA Maintenance (if required)
	5	IVA Science
	6	IVA Science
	7	Off Duty Day
	8	IVA Science
	9	Long EVA day - 1 EVA
	10	Suit Maintenance, IVA Science
	11	IVA Science
	12	Long EVA day - 1 EVA
	13	IVA Science
	14	Off Duty Day
	15	IVA Science
	16	Long EVA day - 1 EVA
	17	Support Glove Swap, IVA Science
	18	IVA Science
	19	Long EVA day - 1 EVA
	20	IVA Science
	21	Off Duty Day
	22	IVA Science
	23	Long EVA day - 1 EVA
	24	Long EVA day - 1 EVA
	25	IVA Science
	26	IVA Science, Suit Maintenance
	27	IVA Science
	28	Off Duty Day
	29	Long EVA day - 1 EVA
	30	Trash Stowage, IVA Maintenance
SH / HLS	31	Prep for Uncrewed Ops, Drive to HLS, Reconfigure LTV, Ingress HLS
HLS	32	Prepare for Ascent
	33	Ascent

NASA's full ABC missions begin with 4 crew arriving on the Lunar surface in the Human Landing System (HLS). Following touchdown, the crew remains in the HLS the rest of the day and the next day, before preparing for HLS egress on surface day 3. On surface day 3, the SH crew egress the HLS and drive the Lunar Terrain Vehicle (LTV) to the SH. Once at the SH, the Lunar SH timeline begins. Surface day 3 is detailed below in Table 7.

Table 7 Surface Day 3 Timeline

Element	Egress HLS, Ingress PR, Retrieve Logistics	Crew A (min)	Crew B (min)
HLS	Crew 1 & 2: Sleep	360	360
HLS	Crew 1 & 2: Post-sleep	60	60
HLS	Crew 1 & 2: Pre-EVA PMC	5	5
HLS	Crew 1 & 2: Final HLS Uncrewed Ops	60	60
HLS	Crew 1 & 2: EVA Prep	90	90
EVA	Crew 1 & 2: EVA Pre-breathe	30	30
EVA	Crew 1 & 2: Depress, Open Hatch	30	30
	Drive to ABC		
EVA	Crew 1 & 2: Descend HLS	20	20
EVA	Crew 1 & 2: Grab contingency sample and store near HLS	15	15
EVA	Crew 1 & 2: Reconfig LTV from uncrewed ops, test drive	45	45
EVA	Crew 1 & 2: Drive to Artemis Base Camp	30	30
EVA	Crew 1 & 2: Perform visual / optical inspection of SH	60	60
EVA	Crew 1 & 2: Remove science tool and sample kit, configure for SPLC ops	15	15
	Ingress Surface Habitat		
EVA	Crew 1 & 2: Don fall protection, ascend hab lander	20	20
EVA	Crew 1 & 2: Initial Suitport (SP) Prep	5	5
EVA	Crew 1 & 2: SP Ingress (EVA)	30	30
SH	Crew 1 & 2: SP Ingress (IVA)	5	5
SH	Crew 1 & 2: Post EVA (IVA)	45	45
	Initial Habitat Checkout, IVA Ops		
SH	Crew 1 & 2: Meal	30	30
SH	**Crew 1 & 2: Initial checkout of habitat**	60	60
	IVA Maintenance		
SH	Crew 1 & 2: IVA Tool Gather	10	10
SH	Crew 1 & 2: IVA Maintenance	150	150
SH	Crew 1 & 2: IVA Tool Stow	10	10
	Day Close Out		
SH	Crew 1 & 2: Evening Prep Work	15	15
SH	Crew 1 & 2: DPC	10	10
SH	Crew 1 & 2: Unscheduled	20	20
SH	Crew 1 & 2: Pre-sleep	60	60
SH	Crew 1 & 2: Sleep	150	150

The crew conducts an external inspection of the SH, ingress the cabin, and begin the SH mission. The next day, surface day 4, the SH crew embark on their first EVA, dedicated to any required external

SH maintenance. After completing the EVA and post-EVA activities, the SH crew receives their logistics and follows the previously described logistics procedure. Surface day 4 is detailed in Table 8 below.

Table 8 Surface Day 4 Timeline

Element	Day Start	Crew A (min)	Crew B (min)
SH	Crew 1 & 2: Crew Sleep	360	360
SH	Crew 1 & 2: Post Sleep	60	60
SH	Crew 1 & 2: Don LCVG and Biomed	25	25
SH	Crew 1 & 2: Morning DPC	10	10
SH	Crew 1 & 2: Morning Prep Work	15	15
SH	Crew 1 & 2: Meal	0	0
	IVA Prep		
SH	Crew 1 & 2: PMC	15	15
SH	Crew 1 & 2: EVA Tool Gather	30	30
	EVA Operations		
SH	Crew 1 & 2: SP Egress (IVA)	20	20
EVA	Crew 1 & 2: SP Egress (EVA)	10	10
EVA	Crew 1 & 2: Don Fall Protection, Descend SH Ladder	20	20
EVA	Crew 1 & 2: Doff Fall Protection	0	0
EVA	Crew 1 & 2: SH Maintenance / Logistics Retrieval via EVA	240	240
EVA	Crew 1 & 2: EVA Utlization	0	0
EVA	Crew 1 & 2: Don Fall Protection, Ascend SH Ladder	20	20
EVA	Crew 1 & 2: Doff Fall protection, ingress SH Airlock	0	0
EVA	Crew 1 & 2: SP Ingress (EVA)	30	30
SH	Crew 1 & 2: SP Ingress (IVA)	5	5
SH	Crew 1 & 2: Post EVA	45	45
	Post EVA IVA Ops		
SH	Crew 1 & 2: Post EVA PMC	15	15
SH	Crew 1 & 2: Post EVA Tool Stow	30	30
	Logistics Receiving		
SH	Crew 1 & 2: Open Hatch, Unload SPLC, Close Hatch	10	10
SH	Crew 1 & 2: Stow Consumables	30	30
	Day Close		
SH	Crew 1 & 2: Routine Ops (Housekeeping)	30	30
SH	Crew 1 & 2: Evening Prep Work	15	15
SH	Crew 1 & 2: DPC	10	10
SH	Crew 1 & 2: Unscheduled	125	125
SH	Crew 1 & 2: Presleep	120	120
SH	Crew 1 & 2: Crew Sleep	150	150

Following this, the crew has their first standard day on surface day 5. During the rest of the mission the crew conducts 2 EVAs a week and off-duty days once a week. Standard IVA only workdays, off-duty days, and EVA days are detailed in Table 9, Table 10, and Table 11, respectively, below.

Table 9 Standard IVA Only Day Timeline

Element	Day Start	Crew A (min)	Crew B (min)
SH	Crew 1& 2: Sleep	360	360
SH	Crew 1& 2: Post Sleep	180	180
SH	Crew 1& 2: Morning DPC	10	10
SH	Crew 1& 2: Morning Prep Work	15	15
SH	Crew 1/2: Exercise / Housekeeping	60	60
SH	Crew 1/2: Housekeeping / Exercise	60	60
SH	Crew 1& 2: Housekeeping	30	30
SH	Crew 1& 2: Midday Meal	60	60
SH	Crew 1& 2: IVA Utilization	355	355
SH	Crew 1& 2: Evening DPC	10	10
SH	Crew 1& 2: Evening Prep Work	15	15
SH	Crew 1& 2: PMC	15	15
SH	Crew 1& 2: Unscheduled	0	0
SH	Crew 1& 2: Presleep	120	120
SH	Crew 1& 2: Crew Sleep	150	150

Table 10 Standard Off-Duty Day Timeline

Element	Day Start	Crew A (min)	Crew B (min)
SH	Crew 1 & 2: Sleep	360	360
SH	Crew 1 & 2: Post-sleep	180	180
	Scheduled Tasks		
SH	Crew 1: Exercise Crew 2: PFC, Off Duty	60	60
SH	Crew 1: PFC, Off Duty Crew 2: Exercise	60	60
SH	Crew 1 & 2: Meal	60	60
SH	Crew 1 & 2: Public Affairs Operations (PAO)	30	30
SH	Crew 1 & 2: WPC	30	30
SH	Crew 1: PMC; Crew 2: Housekeeping	30	30
SH	Crew 1: Housekeeping; Crew 2: PMC	30	30
	Day Close Out		
SH	Crew 1 & 2: Off duty	320	320
SH	Crew 1 & 2: DPC	10	10
SH	Crew 1 & 2: Pre-sleep	120	120
SH	Crew 1 & 2: Sleep	150	150

Table 11 Standard EVA Day Timeline

Element	Day Start	Crew A (min)	Crew B (min)
SH	Crew 1 & 2: Sleep	360	360
SH	Crew 1 & 2: Post Sleep	60	60
SH	Crew 1 & 2: Don LCVG and Biomed	25	25
SH	Crew 1 & 2: Morning DPC	10	10
SH	Crew 1 & 2: Morning Prep Work	15	15
SH	Crew 1 & 2: SP Egress (IVA)	20	20
EVA	Crew 1 & 2: SP Egress (EVA)	10	10
EVA	Crew 1 & 2: Don Fall Protection, Descend SH Ladder	20	20
EVA	Crew 1 & 2: Doff Fall Protection	0	0
EVA	Crew 1 & 2: SH Maintenance via EVA	30	30
EVA	Crew 1 & 2: EVA Utlization	390	390
EVA	Crew 1 & 2: Don Fall Protection, Ascend SH Ladder	20	20
EVA	Crew 1 & 2: Doff Fall protection, ingress SH Airlock	0	0
EVA	Crew 1 & 2: SP Ingress (EVA)	30	30
SH	Crew 1 & 2: SP Ingress (IVA)	5	5
SH	Crew 1 & 2: Post EVA (IVA)	45	45
SH	Crew 1 & 2: PMC	15	15
SH	Crew 1 /2: Post-EVA Exercise/IVA Maintenance	30	30
SH	Crew 1/2: IVA Maintenance/Post-EVA Exercise	30	30
SH	Crew 1 & 2: DPC	10	10
SH	Crew 1 & 2: Evening Prep Work	15	15
SH	Crew 1 & 2: Unscheduled	30	30
SH	Crew 1 & 2: Presleep	120	120
SH	Crew 1 & 2: Sleep	150	150

On the last full day of the SH mission, the crew conducts their “trash stowage” day, which requires the crew to complete the trash stowage procedures described previously. Additionally, the crew then conducts an EVA to place the trash SPLC from the SH cargo port to the LTV, which remotely takes it to the stowage location. Surface day 30 is detailed in Table 12 below.

Table 12 Surface Day 30 Timeline

Element	Day Start	Crew A (min)	Crew B (min)
SH	Crew 1 & 2: Sleep	360	360
SH	Crew 1 & 2: Post Sleep	60	60
SH	Crew 1 & 2: Morning DPC	10	10
SH	Crew 1 & 2: Morning Prep Work	15	15
SH	Crew 1 & 2 PMC	15	15
SH	Crew 1 & 2 Routine Ops (Housekeeping)	30	30
SH	Crew 1/2: Exercise / IVA Maintenance	60	60
SH	Crew 1/2: IVA Maintenance / Exercise	60	60
SH	Crew 1 & 2: Prepare Final trash to SPLC through SP	10	10
SH	Crew 1 & 2: Don LCVG and Biomed	25	25
SH	Crew 1 & 2: Midday Meal	30	30
SH	Crew 1 & 2: SP Egress (IVA)	20	20
EVA	Crew 1 & 2: SP Egress (EVA)	10	10
EVA	Crew 1 & 2: Remove SPLC from Cargo SP, lower to surface	20	20
EVA	Crew 1 & 2: Don fall protection, Descend SH ladder	20	20
EVA	Crew 1 & 2: Doff Fall protection, position SPLC w/ trash on LTV	20	20
EVA	Crew 1 & 2: Don Fall Protection, Ascend SH Ladder	20	20
EVA	Crew 1 & 2: Doff Fall protection, ingress SH Airlock	0	0
EVA	Crew 1 & 2: SP Ingress (EVA)	30	30
SH	Crew 1 & 2: SP Ingress (IVA)	5	5
SH	Crew 1 & 2: Post EVA (IVA)	45	45
SH	Crew 1 & 2: PMC	15	15
SH	Crew 1 & 2: IVA Maintenance	215	215
SH	Crew 1 & 2: IVA Utilization	0	0
SH	Crew 1 & 2: Evening Prep Work	15	15
SH	Crew 1 & 2: Unscheduled	60	60
SH	Crew 1 & 2: Presleep	120	120
SH	Crew 1 & 2: Sleep	150	150

The next day, surface day 31, the crew conducts final system shutdown and egress the SH to return to the HLS, concluding the Lunar SH mission. Following their return to the HLS, the crew begins pre-departure operations for 3 days prior to Lunar surface departure.

IV. Results

Taking the results of the crew time activity assessment, the Lunar SH crew timeline analysts constructed a complete Lunar surface timeline detailing the crew's daily schedule by increments of 5 minutes over the course of the Lunar SH mission. The results of this first timeline provide total durations of crew time activity, and most importantly provide initial insight on what time could possibly be dedicated for utilization. Following the construction of this timeline, crew time data was extracted to further investigate maintenance requirements and utilization potential.

Following the development of the initial Lunar SH crew timeline, the total crew time by activity was evaluated and is detailed in Table 13 and Figure 3. The activities are excluding all possible maintenance or utilization times.

Table 13 Total Crew Time per Activity over Lunar SH Mission

Activity	**Crew Time (CM-hr)**
Sleep	476.0
Post Sleep	126.0
Presleep	110.0
Meal	39.0
Unscheduled Personal	83.2
Conference/Tag Up	17.0
PAO	4.0
Work Prep	24.0
Routine Ops	68.0
Outfitting	2.0
Medical	21.7
EVA	26.2
Logistics	2.7
Exercise	45.0
TOTAL	**1044.7**

Combining the crew time results for each crew activity, there is a total of 1044.7 crew hours scheduled between non-work and work activities, excluding maintenance and utilization activities. Assuming a 2 crew, 28-day mission contains 1,344 possible crew-hours, the results leave just over 299 crew hours for utilization and maintenance. Again, anticipating the high estimate of 22.4 crew hours for preventive maintenance, the utilization crew time is reduced again to over 267 crew hours. Figure 4 displays the resulting utilization times with respect to the total corrective repair crew time distribution.

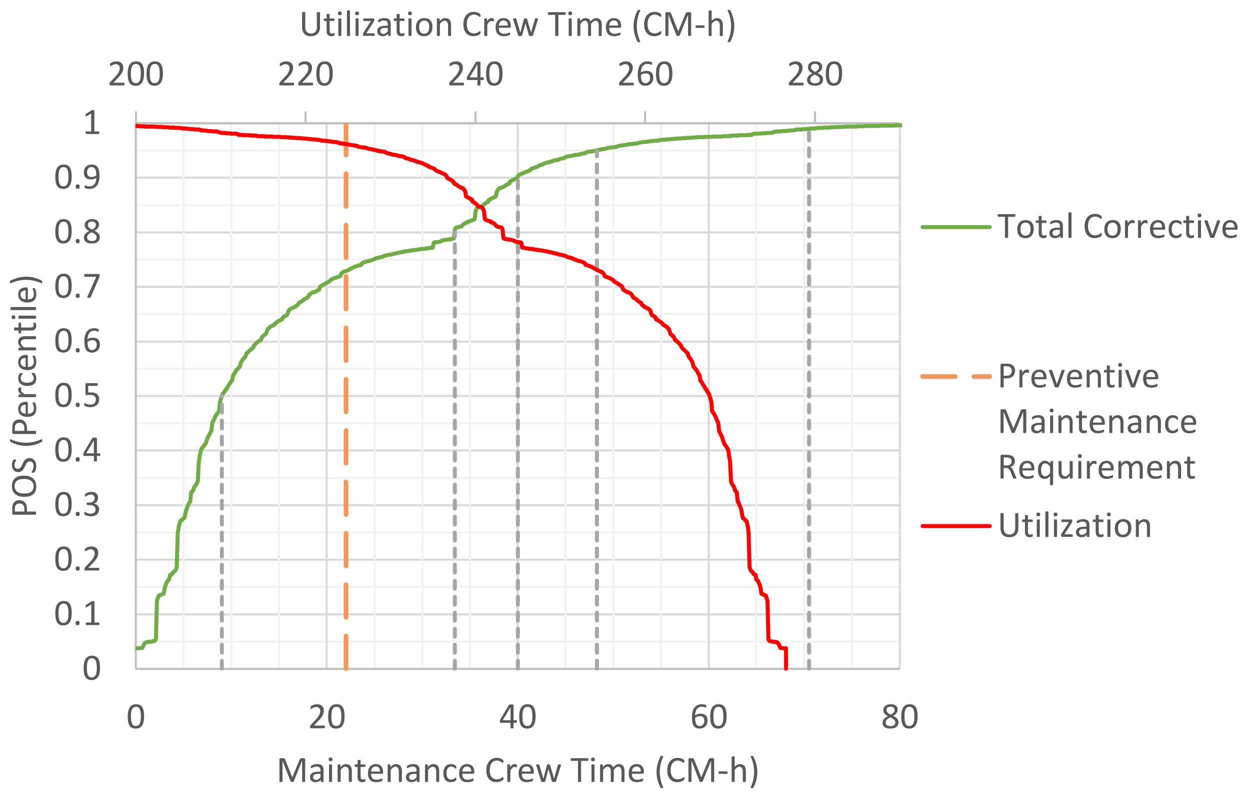

Figure 3 Crew Time Distributions for Corrective Repairs over Lunar SH Mission

Adding to the results shown in Figure 2, Figure 4 includes the resulting utilization distributions, with its respective crew time displayed on the top x-axis. Table 14 below details the distributions shown in Figure 4.

Table 14 Crew Time for Corrective Repairs at Select POS Values and Resulting Utilization Crew Time

POS (Percentile)	Crew Time on Corrective Maintenance (CM-hr)	Utilization Crew Hours (CM-hr)	Crew Time on Preventive Maintenance (CM-hr)	Crew Time Percent on Maintenance	Crew Time Percent on Utilization	Crew Time on Other Work Activities
0.50	9.0	263.9	22.4	6.1%	51.8%	42.1%
0.81	33.4	239.5	22.4	10.9%	47.0%	42.1%
0.90	40.0	232.9	22.4	12.2%	45.7%	42.1%
0.95	48.3	224.6	22.4	13.8%	44.0%	42.1%
0.99	70.5	202.4	22.4	18.1%	39.7%	42.1%

Table 14 details the crew time percentages spent on maintenance and utilization with respect to the total crew time spent on work. To reach the percentage, each metric- maintenance, utilization, and the remaining categories- are divided over the denominator of total work hours, which totals just over 509 crew hours. Figure 5 shows the distribution of crew time activities with the finalized expected corrective maintenance and utilization crew times.

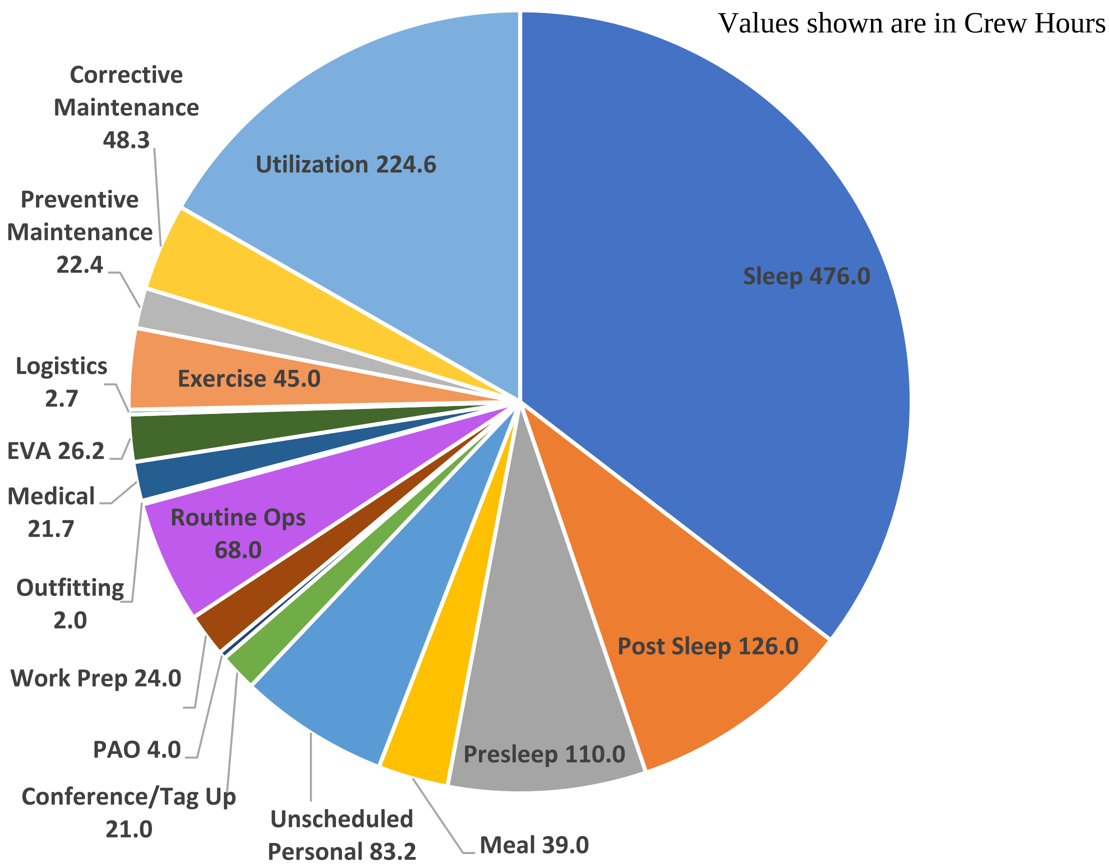

Figure 4 Total Crew Time Distribution of Activities over Lunar Surface Mission

V. Conclusion and Future Work

This assessment proves the importance of a collaborative effort of detailing mission operations of new, innovative human spaceflight missions that encompass diverse fields of study. Multiple system and activity experts across NASA and its partners worked with crew timeline and mission operation analysts in order to create a cohesive and realistic mission timeline for a crewed Lunar SH mission. The results of the study accommodate all crew health and safety expectations, EVA and exploration goals, maintenance and supportability requirements, and science objectives into one detailed mission timeline. The methodology of this assessment is being directly applied to other potential NASA human spaceflight missions, including lunar and Mars mission.

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