Predicting Crew Time Allocations for Lunar Orbital Missions Based on Historical ISS Operational Activities

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As the National Aeronautics and Space Administration continues to define candidate architectures for the planned lunar "Gateway", it will be necessary to have a detailed understanding of how the crew will inhabit, operate, and maintain the spacecraft. The nature of the Gateway vehicle systems configuration and operations will have a direct impact on the scope of work activities required of the crew. Crew work schedules are sensitive to variations in spacecraft architecture, visiting vehicle activities, and logistics operations – particularly within short duration missions as initially planned for the lunar Gateway. These system and operational configurations must be taken into account when planning for crew time availability to conduct science activities on Gateway missions.

This paper presents a methodology that is used to predict crew time distributions for lunar Gateway missions, as applied in NASA's Exploration Crew Time Model (ECTM). The process utilized for evaluating crew time distributions is based on the categorization of all crew activities into a standardized ontology. Historical ISS daily crew timeline data from July 20, 2011 (post STS retirement) to present day was captured via the Operational Planning Timeline Integration System (OPTimIS) database and characterized according to the standardized ontology. This process enabled correlation and statistical analysis of the ISS data according to common mission parameters such as crew size, ECLSS system design, vehicle traffic operations, and logistics delivery operations. The results of the statistical analysis are a set of crew time distributions for each activity category. These distributions are then utilized within the ECTM to examine crew time allocations based on mission parameter inputs, which serve to characterize the Gateway mission configurations.

Results for predicted crew time allocations for representative short duration Gateway missions are presented. These results can be used to evaluate crew schedule availability for science and utilization activities. Variations in expected mission architectures and mission operations are accounted for to correct crew time predictions. The analysis is being leveraged to plan utilization capability objectives that are achievable on the Gateway missions, as well as inform the viability of various mission architecture options.

I. Nomenclature

CTBE	= *Cargo Transfer Bag Equivalent*
ECLSS	= *Environmental Control and Life Support System*
ECTM	= *Exploration Crew Time Model*
EMAT	= *Exploration Maintainability and Analysis Tool*
EVA	= *Extra-Vehicular Activity*
ICOM	= *Integrated Crew Operations Model*
ISS	= *International Space Station*

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IVA = *Intra-Vehicular Activity*
MADS = *(ISS) Maintenance Data Collection*
MDC = *(ISS) Maintenance Analysis Data Set*
MTBF = *Mean Time Between Failures*
OPTimIS = *Operational Planning Timeline Integration System*
USOS = *United States Orbital Segment*

II. Introduction

As the lunar Gateway concept continues to mature as part of NASA's current human spaceflight plans, there is an increasing need to understand how the distribution of crew time on the Gateway may be impacted by vehicle design as well as variations in mission operations. Historically, planning crew schedules and providing for utilization time on the International Space Station (ISS) has been a maturing process that faces challenges arising from maintenance requirements, logistics management, as well as constantly rotating crew increments. Experience on ISS indicates that the crew is sometimes unable to maximize the amount of research that can be conducted on the station due to the amount of crew time tied up in normal operational activities. In order to ensure that research goals and objectives are successfully achieved on the planned lunar Gateway missions, it will be critical to ensure that crew time requirements do not over burden the crew and that the schedule allows for ample time devoted to science and other utilization activities.

Despite its unique architectural and operational characteristics, the ISS provides an opportunity to evaluate the time demands involved in space mission operations. The results from studies of ISS crew time allocation can be used to help predict crew time availability for other human exploration missions such as lunar Gateway missions.

The ISS is not a direct analog for most future exploration missions. Crewed missions to the lunar Gateway, the lunar surface and eventually Mars will include new habitation systems and resupply operations. Future missions will have durations that vary substantially from ISS and require different levels of crew autonomy. However, by establishing baseline crew time distributions for standardized tasking based on historical ISS data and applying specific mission operation parameters such as maintenance, traffic, and EVA operations, it is possible to extrapolate expected demands on crew time usage for future missions.

Previous studies aimed at examining historical ISS crew time usage established baseline crew time allocation estimates for work and non-work activities. These estimates were used in the development of a crew time model, which has been applied to initial predictions for the distribution of crew time and the availability of crew time for science and utilization on deep space missions [1]. This paper describes a recent effort to perform a more expansive analysis of ISS data that enhances the understanding of historical crew time expenditures on the ISS, applying an expanded definition of crew activity categories and expanding the set of ISS data that was examined. The results of this study are a set of standardized, activity specific baseline crew time allocations that are based on defined spacecraft and mission parameters. These allocations can be applied to the evaluation of Gateway crew time distributions, by adjusting the input parameters to account for the Gateway design and expected operations.

The Exploration Crew Time Model was applied to evaluate a representative 30-day crewed lunar Gateway mission to assess sensitivities and predict availability for science and utilization.

III. Crew Time Planning on ISS

Crew time has historically been a limited resource on the International Space Station (ISS). Although the amount of time that crew spends on certain activities is predictable, the amount of time spent on other activities, such as repair and maintenance, logistics management, exercise, medical, and others are more difficult to anticipate and can potentially over burden the crew. Therefore, United States Orbital Segment (USOS) crew scheduling is carefully planned and managed by NASA's Operations Planning team at the Johnson Space Center, in coordination with the partnering international space agencies that form the ISS Program.

The ISS Program employs specific groundrules and protocols for managing crew schedules, which are set up to allocate time according to a set of defined activity categories [2]. Crew time is allocated within a nominal 24-hour crew day using daily task lists, in which activities are organized into duty (work) operations and off-duty (non-work) time. There are eight major categories of on-duty activities, which include: Utilization, Vehicle Traffic Operations, Medical Operations, Routine Operations, On-Board Training, Maintenance, Outfitting, and EVA. Off-duty activities include: Sleep, Meal, and Pre/Post sleep periods which account for personal and hygiene activities. Actual completed activities may vary within the daily task list, as it is up to the ISS crew's discretion to select how they complete and charge against particular activity category allocations.

Activity specific tasks are allocated and tracked within crew member specific timelines as they are completed. Timeline management is accomplished through the use of the Operations Planning Timeline Integration System (OPTimIS), which integrates various task planning software tools that allow the crew and ground control teams to view daily schedules, receive new task updates and record activities as they are completed. The Operations Planning team uses this data to coordinate the short-term and long-term crew and ground control plans for each ISS Expedition mission.

IV. Data Analysis

Previous crew time availability studies involved the analysis of published ISS Crew Timeline data covering 1,211 Expedition mission days from July 20, 2011 to November 12, 2014 [3]. The beginning of the study period was selected to coincide with the retirement of the Space Shuttle fleet. Prior to the retirement, many ISS upkeep tasks and other activities were performed by visiting shuttle crews. In addition, substantial crew time was devoted to docking and other shuttle related activities while the shuttle was present. Analysis of the post-shuttle period provides for a more representative picture of ISS crew time distribution, which more closely resembles operations for future Deep Space missions.

The ISS Timeline data allows for evaluation of daily crew activities per 24-hour period, down to 5 min increments, for the purpose of conducting statistical analysis of historical variations within individual activities. In previous efforts, a statistical analysis was used to derive baseline crew time "lien" allocation estimates for the primary activity categories (discussed in Mattfeld et al., Ref. [1]). These lien estimates were then used in the development of a model that predicts crew time requirements for exploration missions. This model allowed for the liens to be adjusted according to specific mission and spacecraft characteristics and then predicted crew time demands for a specific exploration mission. The model compared total crew time availability with the predicted time requirements in order to determine the sufficiency of available crew time. If there was sufficient time available to cover all predicted crew time liens, it was then assumed that any surplus time was available for utilization activities.

While the previous study has provided a capability for providing initial estimates for crew time availability, there were various limitations that limited the ability to accurately predict detailed future exploration missions time requirements. That study examined a limited number of primary activity categories without exploring further breakdowns of historical ISS crew time usage according to specific mission operations. As a result, the previous allocation for the maintenance and repair time category did not correlate to any specific repair and maintenance activities. Since repair and maintenance time are a major driver of crew time availability, a more accurate estimate of those demands is required to accurately predict the complete crew time requirements for exploration missions.

Similarly, the increased autonomy required for a crewed mission beyond low-Earth orbit will have an impact on in-flight training and communication activities that can be better understood by evaluating how these tasks vary within the historical ISS experience data. The baseline crew time "lien" allocation estimates produced by the previous study were used as a general guide for estimating crew time expenditure on future Mars missions. However, in order to more accurately predict how mission and vehicle design factors impact particular demands to crew time, it is necessary to investigate historical ISS experience in greater detail. In addition, there are some observable differences between published ISS crew timeline data and planned Expedition schedules which must be better understood. The objective of this paper is to describe the results of this investigation.

For the current study, described in detail in this paper, ISS crew time data was obtained from the OPTimIS Viewer tool, which provides a more detailed analysis of crew time usage. OPTimIS was used to extract an expanded set of ISS crew time data, including an additional 852 days of operation (through the end of 2016). OPTimIS Viewer provides the ability to organize crew activity data through the use of various specific filter categories. Given the variety of systems and operations performed on the ISS, the ability to investigate crew time spent on specific task categories and to correlate crew time usage to spacecraft and mission specific parameters is essential for accurately applying the data to predict crew time requirements for future deep space missions.

The ISS Timeline data captured from OPTimIS was also supplemented with ISS Expedition mission data to incorporate additional operations information such as cargo and crewed vehicle traffic activities, maintenance and repair activities, EVA operations, and resupply events [4]. Expedition mission data was obtained from the NASA ISS operations archives for Expeditions 28 (2011) to 55 (2018) [5]. In addition, maintenance event log data from the ISS Maintenance Data Collection (MDC) as well as the ISS Maintenance Analysis Data Set (MADS) was used to correlate crew time spent on repair and maintenance activities to the specific systems and, if appropriate, repair activities that were executed. These two data sets are used by the logistics and maintenance engineering teams to track historical hardware failures and ISS Program maintenance activities aboard the station.

V. Activity Categorization

A major focus of the crew time study was the establishment of a standardized Crew Time Ontology. Previous crew time availability studies have borrowed from the major activity categorization definitions used for managing ISS crew timelines. In order to investigate historical variations on ISS crew demands within specific activities, the Crew Time Ontology builds upon the ISS-based activity categorization. The Ontology organizes activities into two major groups: Work and Non-work, which is consistent with the definition of On-Duty and Off-Duty activities established by the ISS Operations Planning team. The "Work" category is further divided into Scheduled Operations to include all of the eight major planned and essential on-duty activities normally used for ISS crew time planning purposes. A secondary Operations Preparations & Conference sub-category encompasses related planning and communication activities. The "Non-Work" category represents all other off-duty crew activities performed for daily living. This breakdown is depicted in Table 1.

Table 1. Crew Time Ontology Categories and Activities

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

A. Work Activity Definitions

In order to assess crew time distributions at a discrete level, it was necessary to define the specific sub-activities and operations that make up certain activities. This was necessary so that time allocations could be correlated with specific activities that might take place during ISS operations and on exploration missions. The definition of sub-activities and operation types is shown in Table 2.

Table 2. Crew Time Ontology Sub-Activities and Operation Types

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		

Each category and sub-category of crew activities under the Work Category has a specific definition.

1. *Scheduled Operations*

- **Standup/Closeout**—Crew tasks involving crew arrival and departure activities, including unpacking and packing of personal effects, increment closeout activities, and rotating crew conferences.
- **Traffic**—Crew tasks involving the management of visiting vehicle operations, including support of Docking/Undocking, Berthing/Unberthing, and Vehicle Relocation activities.
- **Routine Ops**—Crew tasks involving scheduled systems and consumables management, vehicle housekeeping and organization, weekly or monthly software and data upkeep, and scheduled communications testing.
- **Maintenance**—Crew tasks involving the repair and upkeep of the critical life support systems aboard the station to ensure they are operating nominally. These tasks are divided into repair time to correct unplanned failures and scheduled preventive maintenance tasks according to ECLSS system.
- **Outfitting**—Crew tasks involving installation and activation of new hardware and software systems.
- **Medical**—Crew tasks involving fitness checks and monitoring, water and air quality monitoring, contaminant and radiation monitoring, and crew health support and emergency services.
- **EVA**—Crew tasks executing or supporting extra vehicular activities. Pre- EVA operations include suit preparation, airlock depress/repress, crew pre-breath, and station egress. EVA operations include all work and EVA science activities completed during the spacewalk both by the EVA crew and IVA support. Post- EVA operations include station ingress, airlock depress/repress, de-suit, health check.
- **Vehicle Loading/Unloading**—Crew tasks involving unpacking cargo deliveries from visiting logistics vehicles, as well as packing trash into a departing logistics vehicle for disposal.
- **Routine Logistics Ops**—Crew tasks involving periodic cargo inventory management, extraction of specific stowage items, and inter-module stowage relocation.
- **Training**—Crew tasks involving safety/emergency briefings, crew orientation training, and specific systems or operations proficiency training.
- **Exercise**—Crew time scheduled for cardio and resistive exercise requirements. Includes time spent on equipment set-up and stowage/clean-up.
- **Utilization**—Crew tasks involving scientific research. These tasks are determined by the scientific objectives of each mission that can be accomplished once all other work demands are met.

2. Operations Preparation and Conference

- **Work Prep—**Crew tasks involving work task planning and set-up.
- **Public Relations—**Crew tasks involving media interviews and public (station to ground) conferences.
- **Conference—**Crew tasks involving entire crew team mission briefs/de-briefs.
- **Tag-ups—**Crew tasks involving work task procedures review and individual schedule/operations consultations between in-space crew and ground control teams.

B. Non-Work Activity Definitions

The off-duty or "Non-Work" category represents all daily crew living activities subject to personal schedule and preference.

- **Personal—**Crew time spent on private family conferences and R&R.
- **Sleep—**Crew time devoted entirely to individual rest. 'Sleep' does not include hygiene or pre/post sleep activities. Within the ISS Pre-Sleep and Post-Sleep crew task data, it is difficult to distinguish between the morning and evening meals and personal hygiene. Therefore pre/post sleep activities are considered to form part of the meal category in order to account for breakfast and dinner crew time expenditure.
- **Meal—**Crew time devoted on morning, midday, and evening meals. Includes time spent on food preparation and clean-up, as well as Pre/Post sleep hygiene activities which may overlap with morning and evening meal times.

The Crew Time Ontology provides a common framework for evaluating historical crew time usage on the ISS. The following sections will describe the method by which the authors evaluated historical crew operations aboard the ISS in reference to the activities defined within the Crew Time Ontology, in order to develop time allocations per individual crew activity. The time allocations serve as baseline for estimating crew time demands on future human space explorations missions.

VI. Analysis Results

The historical ISS crew timeline data derived from OPTimIS includes various data fields that were captured in support of the analysis described. These data fields include the following information:

- Activity task descriptions
- Crew task ops notes
- Task completion status
- Crew operators involved per task
- Activity start time & end time

The OPTimIS Viewer Tool categorizes crew activities via "filter categories". However, for the purpose of this analysis, the activity categorization defined through these filters did not provide an appropriate mapping to the Crew Time Ontology. Therefore, the ISS crew time data derived from OPTimIS required preprocessing to allow for a re-categorization of crew activities within the established Ontology. The data set was pre-processed by sorting activities according to year/day/time, removing 'REMINDERS' which are not relevant for crew time analysis, and removing activities which the ISS Expedition crew failed to complete.

The pre-processed ISS crew time data was then re-categorized in accordance with the Crew Time Ontology. Re-categorization involves passing the data through a set of libraries. Libraries use information from the activity task name, the ops note, and the activity's filter categories to map ISS crew activities to the categories established within the Ontology. These libraries process the data using two methods:

- Keyword categorization— a set of unique identifiers that map to a particular activity category
- Filter Category Rules—specific combinations of ISS filter categories attributed to each activity.

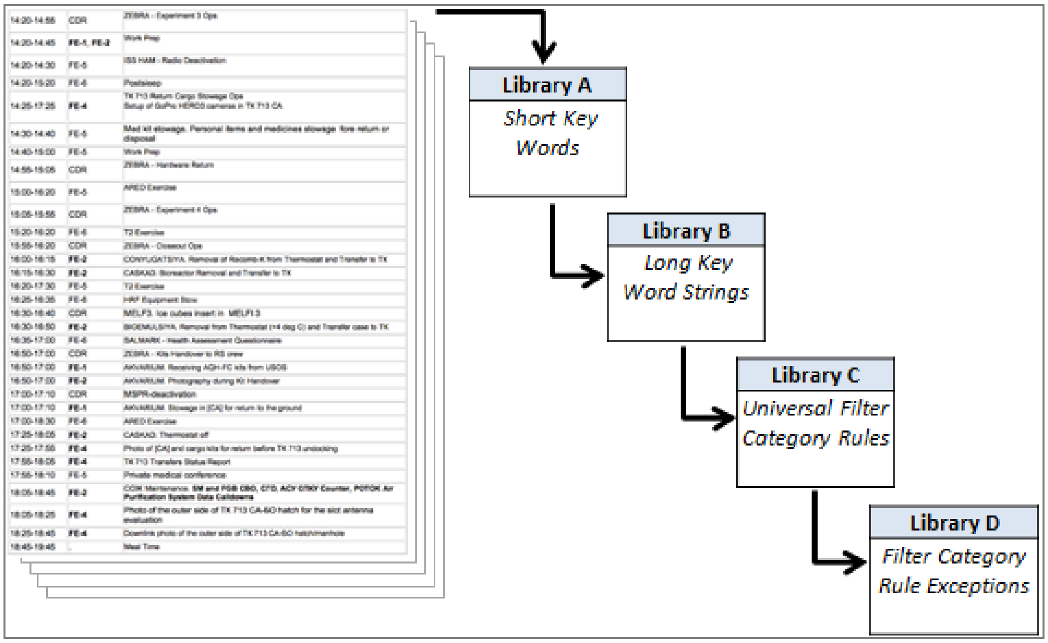

Fig. 1 Data Processing via Libraries for Activity Categorization

As depicted in Figure 1, pre-processed crew time data is passed through the various libraries, in sequence, in order to re-categorize data as accurately as possible. First, Library A identifies all categories an activity could potentially belong to by checking if short key words are contained in an activity's task name or ops note. Next, Library B re-categorizes activities which are mapped to multiple categories by using longer, more specific, keywords that specifically address conflicts. Lastly, Library C and D use Filter Category Rules to identify any activities which have a combination of filter categories that have shown to consistently map to a category, thereby prioritizing and re-categorizing them appropriately.

The library categorization process is necessary because often multiple different terms may be used to describe a single activity type within the textual crew activity data. For example, an astronaut exercising may be described as "exercise", "work out", "running", etc. An exercise activity might also be described using the specific piece of equipment, "treadmill", "TVIS", etc. The library will capture all of these terms in order to properly characterize the activity. Prioritization is often required because search terms from multiple categories can show up in a single text description. For example, astronauts may exercise as part of activities to prepare for an EVA. In this case, the activity should be categorized as EVA rather than exercise.

Following activity re-categorization, the ISS crew time data was analyzed to produce statistics regarding the time distribution for individual activities. The results of this analysis indicate historically how much time has been spent by ISS crewmembers on each activity, sub-activity, or operation. The statistical analysis is summarized as an allocation per activity.

Each crew time allocation is derived according to a specific allocation method that correspond to the activity type. The allocation method is driven by specific mission or spacecraft parameters that could vary between missions. The most common allocation methods are allocated on a 'Per Week', or 'Per Crewmember Week' basis. 'Per Week' allocations specify the total amount of hours spent per week on a specific activity, regardless of the number of crew. 'Per Crewmember Week' allocations specify the amount of time spent on tasks that are specific to each crew member. These types of crew time allocations are generally specified on a weekly rather than a daily basis to account for daily schedule variation within the standard work week, including days off.

Certain activities with the crew ontology have an alternate allocation method. These methods capture the parameters that most directly dictate the amount of time required. The time allocation derived for the Traffic activity subcategories – docking/undocking, berthing/unberthing, vehicle relocations – are on a 'per event' basis. In order to derive an average 'per event' time allocation, the OPTimIS data set was combined with external ISS Expedition mission data, which included specific vehicle docking/undocking, berthing/unberthing, and relocation events that took place during Expeditions 28-55. It was assumed that all the Traffic activities directly associated with docking/undocking, berthing/unberthing, and vehicle relocations happen on the same day of the specific mission event. The crew time spent on Traffic events represents an average across all the ISS Traffic events identified within the 2011-2018 Expedition mission time period.

Crew Time spent on maintenance is divided into Corrective Repair Activities and Scheduled Preventative Activities. The historical ISS crew time spent on these two activity categories was further separated by critical system and further down to the component level for repair events. This was achieved by analyzing the ISS MADS and MDC datasets to derive average time spent per system according to either maintenance event. The result was then adjusted by the daily maintenance or repair event frequency across all ISS Expedition missions included within the MDC dataset, to derive an estimate of the average crew time spent conducting preventative maintenance or corrective repair on each system per mission day. Since these activities are driven by the specific systems architecture, it was not realistic to produce a single hourly maintenance and repair time allocation.

The time allocation derived for the Outfitting activity subcategories – Outfitting Hardware and Outfitting Software – are on a "Per Outfitting Event" basis. In order to derive an average 'per event' time allocation, all outfitting activities for each corresponding subcategory were first added. Then, distinct "outfitting hardware" and "outfitting software" activities were manually counted by filtering for outfitting activities within the dataset and going through activity descriptions individually. Dividing the total amount of time spent on outfitting and dividing by the number of distinct outfitting events allows for reporting the outfitting time allocation as "Per Outfitting Event".

The EVA category is allocated on a 'Per EVA Event' basis. EVA time data was evaluated based on USOS spacewalk events during Expeditions 28-55. EVA activities include the following subcategories: Pre-EVA, EVA spacewalk, and Post-EVA. Each sub-category is allocated separately. Crew time data was correlated with EVA activity reports to match crew time allocations to specific EVAs. "Pre" and "Post" EVA events were assumed to occur within a 2-day window before and after the EVA date specified. Using the categorized OPTimIS dataset, EVA activities were filtered using the corresponding dates, to indicate which EVA activities belong to a particular EVA event. The total amount of crew time spent on each sub-activity per EVA event was derived. The average crew time spent on all EVA events is reported by averaging results across all EVA events.

The Logistics loading/unloading subcategory is allocated per individual loaded/unloaded Cargo Transfer Bag Equivalent (CTBE). This is a standard measure of cargo volume in ISS operations. The crew time allocation for loading or unloading of logistics represents an average time per CTBE across all the ISS vehicle arrival and departure mission events. In order to derive average crew time spent loading or unloading cargo from visiting vehicles, the OPTimIS data set was correlated with ISS Expedition mission data, including the following information:

- Vehicle arrival/departure dates for Expeditions 28-55 and vehicle type
- The total consumables delivery quantities associated with each vehicle arrival, as well as total trash offloaded onto departing vehicles for disposal.

A description of each of the allocation methods and results are provided in Table 3. These results are expressed as average hours across ISS expedition missions and are represented according to the specified allocation method. Standard Deviation per ISS expedition mission is included to show the variation of categories throughout the different expedition missions. All results are normalized to account for variations in Expedition durations.

Table 3. ISS Activity Allocation Results

Category	Average Hours	Standard Deviation across ISS expedition (hrs)	Allocation Method
Standup/Closeout	43.4	N/A	Per crew mission
Traffic Docking/Undocking	4.1	N/A	Per docking event
Traffic Berthing/Unberthing	6.4	N/A	Per berthing event
Traffic Vehicle relocations	10.0	N/A	Per relocation event
Routine Ops	12.8	2.5	Per week
Corrective Repair	N/A	N/A	Specific to Mission Architecture
Scheduled Preventative Maintenance	N/A	N/A	Specific to Mission Architecture
Outfitting Hardware	1.7	N/A	Per Outfitting Event
Outfitting Software	0.4	N/A	Per Outfitting Event
Medical	1.7	0.3	Per crewmember week
EVA Prep	23.1	N/A	Per EVA Event
EVA - Spacewalk	9.0	N/A	Per EVA Event
Post EVA	7.4	N/A	Per EVA Event
Logistics Loading/Unloading	0.1	N/A	Per CTBE loaded/unloaded
Routine Logistics Ops	11.6	2.5	Per week
Training	1.6	0.4	Per crewmember week
Exercise	14.3	1.0	Per crewmember week
Work Prep	16.1	5.3	Per week
Public Relations	1.2	0.3	Per crewmember week
Conference	3.9	0.5	Per crewmember week
Tag-Ups	0.2	0.1	Per crewmember week
Personal	0.4	0.1	Per crewmember week
Sleep	60.8	1.0	Per crewmember week
Meal (incl. Pre-Sleep & Post-Sleep)	29.5	0.5	Per crewmember week

VII. Model Development & Case Study

Following the statistical analysis of historical ISS crew time data and the development of baseline allocations based on the Crew Time Ontology, an Exploration Crew Time Model (ECTM) was developed to predict crew demands on future exploration mission concepts. The ECTM combines the activity-specific crew time allocations with the following parameters used to define a mission case:

- Mission duration (days)
- Crew Size
- # EVAs

- # Vehicle Docking/Undocking Events
- # Vehicle Berthing/Unberthing Events
- # Vehicle Relocation Events
- # Delivered Cargo CTBEs
- # Trash CTBEs Offloaded
- Outfitting Event
- Systems Architecture.

A. Adjusting Crew Time Allocations

In order to accurately predict crew operations on lunar Gateway missions, it is necessary to make some adjustments to the ISS-derived Crew Time allocations. The crew allocations described in the previous section serve as an initial framework for future human exploration missions, however they represent the specific crew demands and mission operations architecture unique to the ISS. Therefore, the following assumptions were made to adjust the allocations, which are expected to deviate away the most from ISS experience for future lunar Gateway mission.

1. Standup/Closeout

The current planning for the lunar Gateway mission campaign results in roughly one crewed mission per year with no overlap between crewed increments. The Gateway will enter an uncrewed period between crewed missions, which will require that each visiting crew activate/checkout the life support systems upon arrival and place the systems into an uncrewed state prior to departure. There is little equivalent historical experience of these types of operations aboard the ISS, given that the station is continuously crewed and not operated autonomously in a dormancy period. Therefore, the adjustment to this allocation for Gateway mission assumes the crew will spend a total of 48 hours per mission for standup and closeout activities.

2. Maintenance & Repair

The critical systems expected to form part of the future Gateway architecture will benefit from additional improvements in reliability and maintainability. These systems are being designed as a simplified Open-Loop architecture. Therefore, the total amount of Gateway crew time spent on repair and preventative maintenance activities is predicted to decrease by 15% from the historical time spent on the ISS.

3. Outfitting

The total amount of time spent by the ISS crew on each outfitting event to install new hardware and software systems may be limited due to the range of Expedition timeline data that was available for the current study. It can be expected that a larger number of new equipment installation events occurred during the early years of the ISS station assembly history (2000-2010). Therefore, it can be assumed the actual amount of crew time required per installation/checkout event will be much higher than the current ISS-derived allocation. The adjusted allocation for Gateway missions assumes a full work day (~8 hours) will be required per outfitting delivery event.

4. Medical

The amount of individual ISS crew time historically spent on medical tasks indicates less than 1.7 hours weekly. It is expected that the majority of physical risks to the Gateway crew will have been identified and mitigated against pre-flight, however there will be some increased time allotted for radiation monitoring. Therefore, the adjustment to the ISS-derived allocation assumes Gateway crew members will spend a full 2 hours per week on Medical-related tasks.

5. EVA

Historical EVA operations on the ISS involve the coordination of various tasks between the crew to setup the Airlock, configure Extravehicular Mobility Unit (EMU) Suits and prepare the selected crewmembers for the spacewalk. Consequently, the current ISS-derived allocation for Pre-EVA includes a significant amount of time that is specific to EVA protocols unique to the ISS as well as specific to EMU suit architectures used on the ISS. Pre-breathe and In Suit Light Exercise (ISLE) alone account for 13 crew time hours on average, which could be reduced with further optimization of the EVA suits. It is assumed that crew Pre-breathe and suit donning tasks will be reduced on the Gateway, therefore the crew time allocation for Pre-EVA events is reduced to 11.6, to account for a 50% optimization.

Post-EVA activities mainly involve airlock repress/depress and EVA closeout activities which are not expected to lower significantly in terms of crew time demand. Although some time reduction of these activities may occur, Post-EVA time is kept the same as a conservative estimate of future Post-EVA crew time requirements. For Spacewalk activities, the ISS-derived crew time allocation represents the range of EVA maintenance, assembly, and science activities historically performed on the ISS. The amount of crew time spent on Spacewalks during Gateway missions is not expected to deviate significantly from ISS experience, so this allocation is also not adjusted.

6. Logistics Loading/Unloading

The amount of ISS crew time spent unloading and loading cargo bags can be dependent on the delivery vehicle (Dragon, Cygnus, ATV, HTV, Progress) which have different design/packing configurations that impact how easily the crew is able to load/unload cargo. However, it is expected that advancements in Radio Frequency Identification (RFID) technology in combination with a smaller crew space will likely significantly lessen time spent on logistics handling during Gateway missions. Therefore, it is estimated that future crew time on the Gateway will be decreased from 0.1 hours (~10 minutes) to 0.08 (~5 minutes) per CTBE loading/unloading.

7. Routine Logistics Ops

The amount of time historically devoted by ISS crew to stowage management, cargo relocation and extraction activities is driven primarily by the size of the station. The ISS is made up of various pressurized modules which are used for equipment and cargo stowage, which can present a significant demand on crew time to track and relocate cargo. The current configuration planned for the Gateway architecture is much smaller, thereby potentially reducing crew time demands from stowage management activities. Therefore, it is expected that routine logistics crew time on Gateway missions will be reduced from a total of 11.6 hours per week to 7 hours per week for these activities.

8. Training

The time devoted by ISS crew on training is mainly due to the amount of onboard training activities that occur while on ISS. It is expected that for short duration Gateway missions more pre-planning and training on ground will occur, reducing training time for crew while on Gateway. Therefore, it is expected that crew time spent on training will lessen for Gateway crew from 1.5 hours per crewmember week to 1 hour per crewmember week.

9. Exercise

The amount of crew time devoted to Exercise activities on the ISS includes both resistive and cardio exercises as well as set-up and stowage tasks that can vary according to the type of equipment used. Future long duration human exploration missions beyond low Earth orbit will require further physical protection requirements to mitigate against increased risks posed to the crew by the deep space and micro-gravity environments. However, the current ISS-derived exercise allocation is consistent with predicted daily exercise requirements for short duration Gateway missions, therefore there is no adjustment to this value.

10. Work Prep

The amount of crew time devoted to Work Prep activities on the ISS is highly dependent on the type and volume of work related operations performed by the different Expedition crews. There is a heavy demand to plan and set-up work operations on the ISS due to the crew make-up and station size. It is expected that the extent of these changes will be lessened for crews on future Gateway missions. Additionally, Work Prep operations in ISS show greater sensitivity relative to mission configuration and objectives, as indicated by the relatively high standard deviation depicted for this activity on Table 3. It is expected that Work Prep time demands on Gateway missions will be reduced due to increased pre-planning prior to crew departure to optimize crew accomplishments on the Gateway during the short duration missions. The crew time allocation for these activities is predicted to be reduced from 16.1 to 7 hours per week.

11. Tag-Ups

The interpretation of historical tag-up time spent by ISS crew members is made difficult by the description semantics used for this activity category within the ISS Crew Timeline data. These tasks are often presented as part of the description of an actual work task recorded by the ISS crew and do not carry their own individual allocation time. Consequently, in order to resolve these overlaps the authors applied a general assumption that tag-up events are generally brief in duration at around 5 minutes per tag-up. Therefore, when analyzing the entire set of ISS Crew Timeline data, the resulting crew time allocation for these activities is representative of the brief crew-to-ground control communication events that occur during nominal work weeks. In order to account for increased communication delays during task-specific tag-up events expected for the lunar Gateway missions, this allocation was increased from 0.2 crew member hours per week to 1 crewmember hour per week.

12. Personal

The amount of ISS crew time devoted to Personal activities, which generally includes private family conference and R&R time, is below what would be expected for the long duration ISS Expedition missions. The Non-work crew activity time allocations are included within ISS scheduling, however the manner in which this time is utilized is up to the crew's discretion. Given the emphasis on tracking Work activities, there is reduced consistency in the recording of actual ISS crew time expenditure on the Non-Work activities such as Personal time. Therefore, it was observed that a large majority of personal-related crew activities were recorded within the ISS timeline data as being part of the Sleep category. To re-categorize this data more appropriately, it was assumed that the extra time recorded within the Sleep category represents R&R time that was not captured within the Personal category. Adding this time into the Personal category increases the allocation from 0.4 hours per crewmember per week to 5 hours per crewmember per week for Gateway missions.

13. Sleep

As discussed previously, the current ISS-based Sleep allocation includes some other Non-Work activities devoted to R&R that would otherwise be attributed to the Personal category. Therefore, the crew time allocation estimated for purely crew Sleep is reduced from 60.8 hours per crewmember per week to 56 hours per crewmember per week to account for current crew health standards that require 8 hours of sleep per day.

Table 5. Adjusted Activity Allocations for Gateway Missions

Category	ISS Derived Allocation (hours)	Adjusted Gateway Allocation (hours)	Allocation Method
Standup/Closeout	43.4	48	Per crew mission
Traffic Docking/Undocking	4.1	*No Change*	Per docking event
Traffic Berthing/Unberthing	6.4	*No Change*	Per berthing event
Traffic Vehicle relocations	10	*No Change*	Per relocation event
Routine Ops	12.8	*No Change*	Per week
Corrective Repair	N/A	*System Specific*	Specific to Mission Architecture
Scheduled Preventative Maintenance	N/A	*System Specific*	Specific to Mission Architecture
Outfitting (hardware & software)	1.7	8	Per Outfitting Event
Medical	1.7	2	Per crewmember week
EVA Prep	23.1	11.6	Per EVA
EVA - Spacewalk	9	*No Change*	Per EVA
Post EVA	7.4	*No Change*	Per EVA
Logistics Loading/Unloading	0.1	0.08	Per CTB loaded/unloaded
Routine Logistics Ops	11.6	7	Per week
Training	1.5	*1*	Per crewmember week
Exercise	14.3	*No Change*	Per crewmember week
Work Prep	16.1	7	Per week
Public Relations	1.2	*No Change*	Per crewmember week
Conference	3.9	*No Change*	Per crewmember week
Tag-Ups	0.2	1	Per crewmember week
Personal	0.4	5	Per crewmember week
Sleep	60.8	56	Per crewmember week
Meal (incl. Pre-Sleep & Post-Sleep)	29.5	*No Change*	Per crewmember week

B. ECTM Mission Scenario Results

The described crew time allocations adjusted for Gateway were integrated into the ECTM. The mission input parameters shown in Table 6 were used to represent a crewed Gateway mission.

Table 6. Gateway Mission Parameters

ECTM Parameter	Mission Case Inputs
Mission duration (days)	30
Crew Size	4
# EVAs	2
# Vehicle Docking/ Undocking Events	3
# Vehicle Berthing/ Unberthing Events	0
# Stationed Vehicle Relocation Events	0
# Delivered Cargo CTBEs	100
# Trash CTBEs Offloaded	20
Outfitting Event?	No
ECLSS Architecture	Open-Loop

In order to produce a more accurate assessment of total crew time spent on Maintenance and Repair activities during the Gateway mission, the specific systems anticipated for the Gateway were evaluated for projected repair and maintenance requirements. The durations listed in Table 7 were used to calculate total preventative maintenance time that can be expected based on the maintenance schedule for each component and the expected crew time per maintenance event, drawn from ISS data. Only those systems which are involved with maintaining a breathable atmosphere are operated during the 30-day crewed duration. The rest of the systems continue operating during the remaining 335-day un-crewed period to ensure vehicle functionality until the next crew mission.

Table 7. Representative Gateway ECLSS Architecture

Critical Systems on Gateway	Operating Duration (Days)
Communications & Tracking	365
Temperature and Humidity Control	365
Trace Contaminant Control System	30
Electrical Power System	365
Guidance, Navigation & Control	365
Carbon Dioxide Removal	30
Atmospheric Constituent Monitoring	30
Command & Data Handling	365
Oxygen/Nitrogen Supply & Distribution	365
Thermal Control System	365
Airlock Gas Recovery	30
Air Circulation & Ventilation	30
Pressure Control and Relief	365

To estimate required repair time for system failure events for this architecture, the authors applied the Exploration Maintainability Analysis Tool (EMAT) [6] to predict crew time requirements for system repair activities. The EMAT tool applies the component reliability data and run time for each system to estimate the expected frequency at which failure will occur across all systems. That expected failure rate can then be combined with time estimated to execute each repair to produce an overall estimate for repair time.

The results produced by the ECTM provide an estimate of the total amount of crew hours spent on each activity during the Gateway mission. By calculating the total amount of crew hours available during the mission, these results are used to calculate the estimated number of crew hours which would be available for utilization or research related activities. There would be a total of 2,880 crew hours available on a 30-day Gateway mission consisting of 4 crew members. The total amount of work and non-work activities performed on this mission given the inputs modelled in the ECTM sum to 2,316 crew hours for the entire crew during the 30-day mission. Therefore, the total amount of remaining crew time not devoted to either work or non-work activities is given as 564 crew hours which could be devoted to IVA utilization activities. This equates to approximately 33 hours per crewmember for a 7-day week. These results are depicted in Figure 2 below.

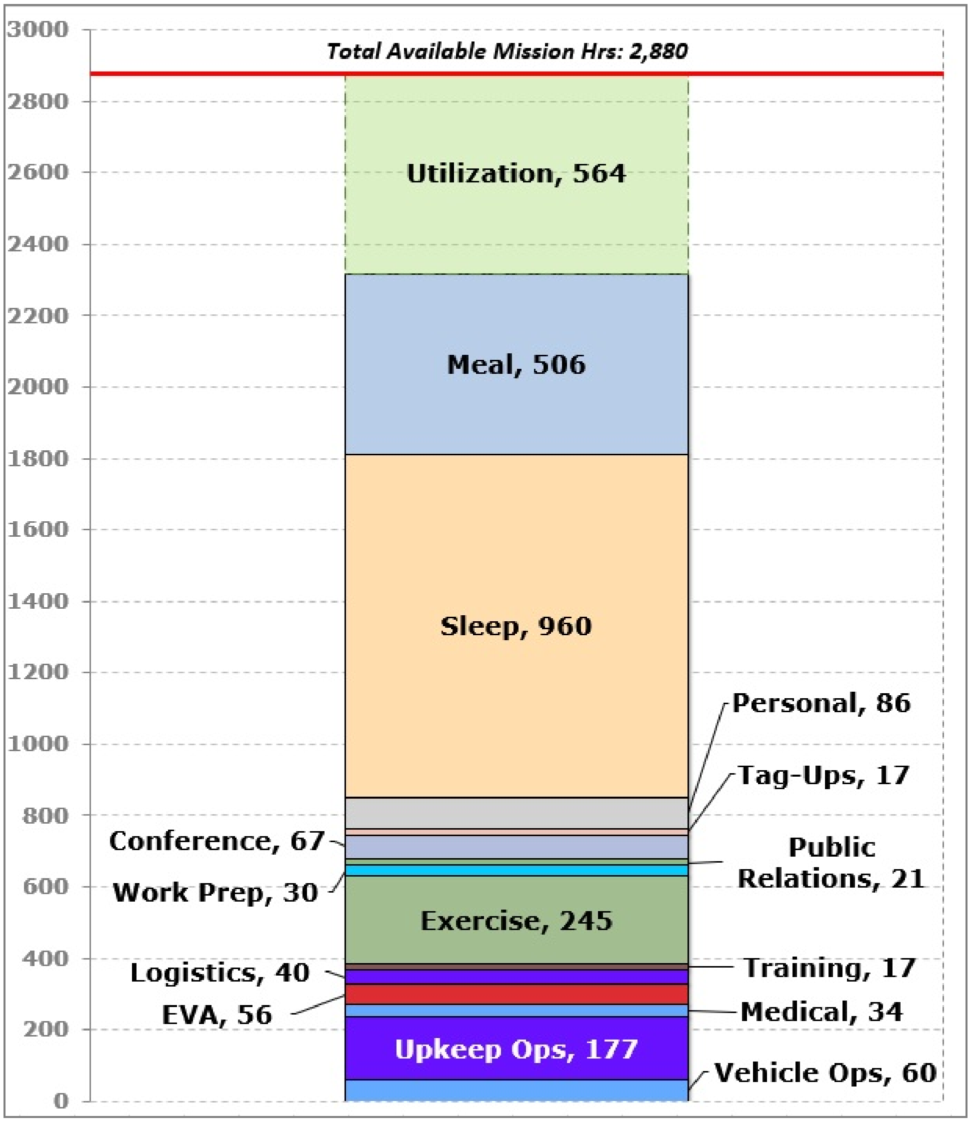

Fig. 2 Crew Time Expenditure for 30-Day Gateway Mission

The 30-day Gateway mission results indicate that the majority of crew time spent on a 30-day Gateway mission will be devoted to daily living requirements, as demonstrated by the 960 crew hours devoted to Sleep and 506 crew hours devoted to Meal categories alone. However, a further investigation of crew time devoted solely to work activities reveals the major drivers to crew demands to accomplish mission requirements. Figure 3 below depicts the breakdown of work only activities to demonstrate the fraction of crew time devoted to each activity during the entire mission duration.

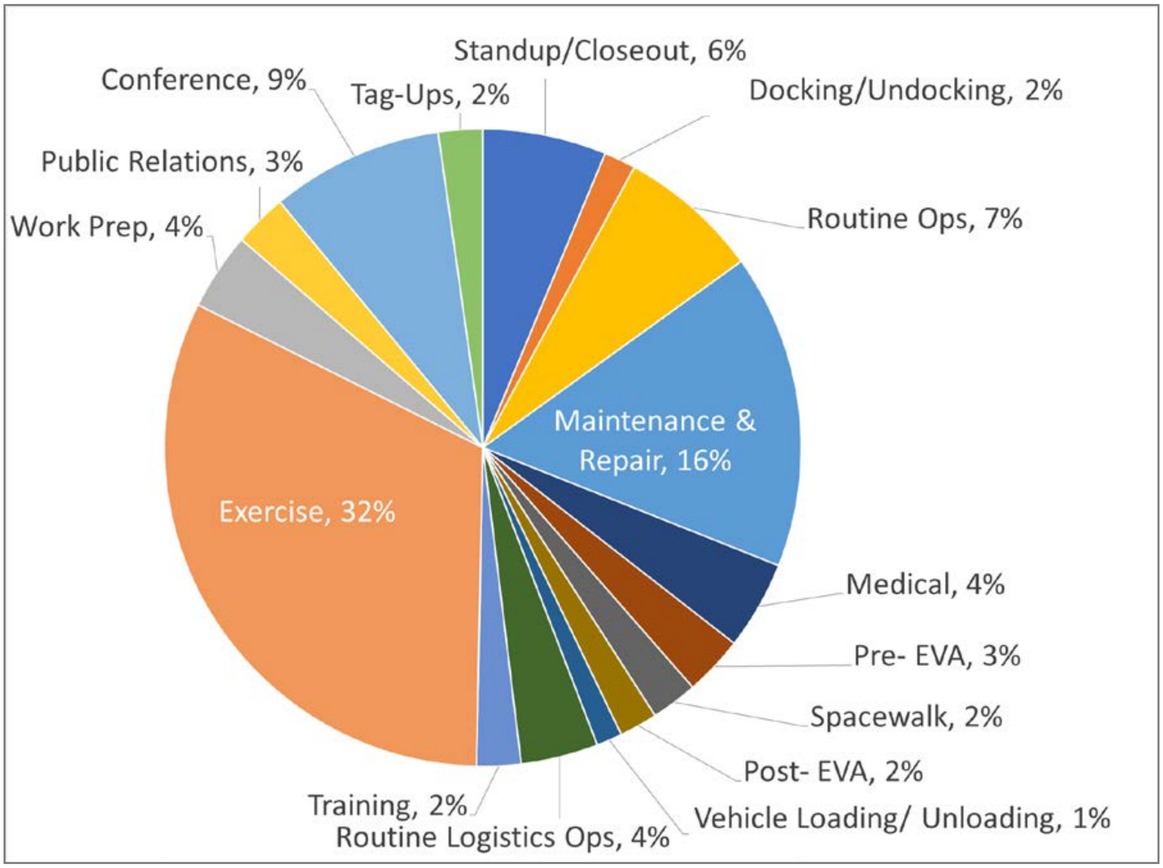

Fig. 3 Breakdown of Crew Expenditure on Work Activities

It is evident that the major drivers to crew work time are Exercise and Maintenance related activities. The Exercise requirement is included as a work activity due to the importance of ensuring that the crew is devoting the required amount of time to maintaining physical health, which should be prioritized over non-work activities that could be rescheduled according to mission demands. Similarly, maintaining the critical systems during the mission is critical for ensuring the habitability of the Gateway vehicle. After these activities are accounted for, Routine operations and Conference tasks can be expected to place a substantial load on crew work demands due to daily vehicle upkeep and Earth communication requirements that can be expected on the mission.

VIII. Conclusion

The results presented in Section VI for a representative Gateway mission demonstrate the value of understanding historical crew time usage on the ISS. After exploring the variations in ISS crew time demands for the various work and non-work activities capturing from the Crew Timeline data, the authors were able to predict the unique time demands a future Gateway mission crew might experience. Calculating crew availability for utilization activities provides a useful estimate that can be applied for planning achievable science objectives on future human exploration missions.

However, it is important to understand that crew time demands are highly sensitive to mission-specific variations, such as increased vehicle traffic operations and system maintenance events. The resulting loads on crew time can cause crew schedules to vary on a weekly or daily basis. Periods of increased crew workload can mean that time devoted to certain activities will be reduced or put off to a later date. This can generally be expected for utilization activities which will be a lower priority activity compared to the activities required for ensuring that the habitation vehicle operates nominally. Therefore, the results produced by the ECTM are presented for the entire mission duration and do not serve to estimate the daily crew schedule.

This study revealed there are specific sensitivities within the various crew activities that can greatly impact overall crew time demands, which could serve as the focus of future investigations. In order to understand the impact of these sensitivities, it would be necessary to further subcategorize individual activities in order to continue exploring the historical ISS crew time data. Specifically, ISS maintenance data can be leveraged further by analyzing maintenance and repair events which occurred throughout the Expedition missions to gain a better understanding of how systems architecture and operability impact time demands. EVA activities can be sub-categorized to a greater level of detail in order to understand how tasks such as pre-breath time and airlock set-up can be optimized on future exploration missions. In addition, variations in ISS training schedules and task specific planning/preparation need to be understood better in order to predict how the increase in communications delays and mission autonomy on future exploration missions will impact how much time can be devoted to activities such as training and work preparation.

There is an opportunity to continue exploring the historical crew experience data from the ISS to better predict which vehicle design configurations and mission operations factors are unfavorable from a crew operations perspective. It is important to ensure crew time demands are fully understood by decision makers tasked with planning future exploration missions to future lunar and Martian environments.

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