A Historical Review of Logistics Mass and Crew Time Demands for ISS Operations

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Following over 23 years of continuously crewed operations on the International Space Station (ISS), NASA is planning to return humans to the Moon and eventually send humans to Mars. ISS operations provide vital data to inform mission analysts as NASA prepares for longer and more complex missions with increased mission endurance. Endurance, defined as crewed operating time between cargo deliveries (or crew launch and return to Earth, if no cargo deliveries), is an important metric when analyzing mission needs. NASA is developing architectures to support sustained deep-space habitats in cislunar space, on the lunar surface, in Mars transit, and on the surface of Mars. Unlike the ISS, these systems will not be continuously crewed. Similar to the ISS however, these systems will not return to Earth for regular refurbishment between missions. Lunar systems will routinely go through long uncrewed periods between crewed missions. The systems on board will need to survive these dormancy periods with no crew present to provide maintenance. Mars systems will experience significantly longer endurance than past experience. Additionally, the inability to have quick aborts to return to Earth increases the need for system reliability, redundancy, and maintainability, as well as plans for contingency operations. However, ISS experience is still useful for planning future missions and remains the best test bed available to predict the requirements of future human missions. This paper analyzes the operational history of the ISS from October 2017 through December 2023, including the mass and items delivered as well as crew time allocations. During this time period, crew on board the ISS logged over 50,000 hours and the station received over 130 metric tons of logistics. Understanding logistics and crew time demands for the ISS will support NASA mission analysts and operation planners as the agency sends humans further out into space.

I. Introduction

Over 50 years after the last Apollo lunar surface mission, NASA is returning to the lunar surface and human spaceflight missions beyond Low Earth Orbit (LEO). Although NASA has not sent astronauts beyond LEO since the final Apollo mission, agency activities since the last Moon landing have provided significant data, lessons, and information on sending humans beyond LEO once again. The International Space Station (ISS) has been continuously occupied by humans for over 20 years. Since the start of its human occupation, the ISS has gone through numerous system and architecture changes. Also, the variety of missions conducted on ISS has continued to increase as the ISS goes into its third decade of service. The level of delivered supplies—referred to in this paper as logistics—to support crew health, vehicle upkeep, and mission objectives provides a snapshot into what is required to support human spaceflight missions and can be used to predict mission needs beyond LEO. In addition to delivered supplies, the activities and tasks completed by the crew provide insight into what needs to be accomplished by crew to both maintain themselves and the vehicle, while achieving mission goals. Gaining an understanding of the crew operational history and logistics deliveries is paramount in developing initial plans for future missions beyond LEO. This paper presents

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an overview of data collection and conditioning methodologies for ISS operational and delivery history, analyzes the collected data, and examines how the data can be applied for planning future missions.

II. Categorizing Logistics and Crew Operations

The two aspects of ISS missions analyzed in this paper are logistics and crew time. Logistics refer to supplies not included in a vehicle's structure that are required in order to protect crew and vehicle health and support mission operations.[1] For this analysis, logistics items were divided into the categories currently defined by NASA's Strategy and Architecture Office (SAO). Logistics are divided into six main categories defined by NASA's SAO: consumables, maintenance, spares, outfitting, utilization, and packaging.[1] The descriptions for each of the logistics categories are summarized below.[1]

- Consumables include commodities that support crew and mission operations and are not a part of any system or vehicle.
- Maintenance items include replacement hardware and tools for scheduled replacements and maintenance activities.
- Spares include spare components or orbital replacement units (ORUs) for addressing potential unplanned failures.
- Utilization includes hardware, equipment, and items that are utilized for mission goals and objectives, including science, and are not required for vehicle operations.
- Outfitting supplies are system or subsystem hardware and components that are delivered for permanent installation.
- Packaging includes the materials required for safe transport and stowage of the logistics items delivered. Packaging can include carrier bags, packing foam, or any other material designed to protect items during delivery.

The mass of logistics delivered, and of what category delivered, can provide a small glimpse of what the ISS mission they are being delivered for may look like. Additional crew members on ISS will directly require more consumables for the crew. New and innovative science missions will likely see a large amount of utilization and outfitting mass being delivered, and new systems being installed may result in an increased amount of maintenance and spares mass delivered. Analysis of different mission types and the logistics required to support them will aid analysts in predicting logistics mass for future missions beyond LEO.

Crew time is a valuable and finite resource during human spaceflight missions. With crew having a limited time during the mission to accomplish goals, it is crucial to understand not only the tasks that need to be completed, but how much time is needed to accomplish the tasks. To know how much time is available for crew to complete science and utilization activities, it must be known how much time the crew will need to complete tasks to maintain their and the vehicle's health.

Table 1. Crew activity categorization.[2]

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

In simple terms, the time to complete what is hoped to be accomplished is constrained by the time to complete what needs to be accomplished.

Crew activities can be divided into two main categories, as shown in Table 1: work and non-work.[2] Scheduled non-work activities include sleep, postsleep, presleep, and meal times. Outside of the scheduled non-work activities, crew members may have unscheduled personal time blocks throughout their time on station. Work activities are reserved for the crew's nominally scheduled work day and are split into two sub-categories: scheduled operations and conferences.[2] Conferences consist of public affair tasks (such as video calls or prerecorded videos) and conferences or tag-ups with the on-orbit crew and potentially the ground crew. Scheduled operations can be described as the hands-on portion of the crew work day and are divided into the following activities: vehicle operations, upkeep operations, outfitting, medical, extravehicular activities (EVAs), logistics, training, exercise, and utilization.[2]

Table 2. Schedule operations activity breakdown.[2]

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	
			Routing Logistics Ops	
		Training		
		Exercise		
		Utilization		

Further explanation of the activities list above is available in Stromgren et al.[2] Vehicle operations, upkeep operations, EVAs, and logistics activities can further be separated into sub-activities, listed in Table 2.

Like logistics needs, how crew members use their time on station is related to the mission goals and objectives. New science missions may require more time to move logistics, complete training, and meet with ground crew operators. A mission with higher EVA needs may see increased crew medical activities and decreased exercise. Crew time data from ISS operations helps inform analysts about typical activity requirements that certain missions may have when planning for future missions.

III. Data Processing Methodology

In order to analyze the operational data of the ISS, the authors developed new processing techniques and utilized previously established techniques to prepare raw ISS data for analysis.[2,3] Logistics and crew time data were collected from separate data sources, but both methodologies follow a similar process of categorizing the raw data into the defined categories outlined in Section II.

A. Logistics

Logistics are logged in the Missions Integration Database Application System (MIDAS). MIDAS contains individual launch delivery manifests to the ISS since the first mission and a consolidated dataset of payloads delivered to the ISS since October 2017. The study in this paper utilizes the data in the consolidated dataset, so the timeline analyzed begins on October 1, 2017. Individual launch manifests, one for each mission, are available in MIDAS but lack the consistent formatting that is available in the complete MIDAS dataset. Because of this, the analysts relied on the complete dataset for analysis but used the individual manifests –containing the same data– as a validation reference, comparing the processor data to what is available in the manifests. For each delivery to ISS, MIDAS contains information on each payload included, including 81 data points per entry detailing the payload. The data of focus for this analysis are item name, quantity, mass, and volume. MIDAS does not denote an SAO defined logistics category (outlined in Section II) for each payload, so the additional data outside of name, quantity, mass, and volume helps aid analysts in identifying the proper category. The authors established a set of keyword libraries that process the complete MIDAS item entry and identify the proper logistics category. The categorization process analyzes four datapoints from the payload's MIDAS dataset for logistics categorization: the payload's name, the payload organization, subcategory, and subsystem. Separate libraries are established for each.

The organization, subcategory, and subsystem libraries list every available organization, subcategory, and subsystem option in MIDAS and contain a set of possible logistics categories for each one. For each payload, the processor examines the libraries for the payload's listed organization, subcategory, and subsystem, and creates a set of logistics category options that were included in each individual library. If this process returns more than one potential logistics category option, the processor relies on a keyword library to identify the logistics category of the payload item. The keyword library contains lists of words and phrases associated with a logistics category, and the processor searches for these words in the item name to identify a category. An example of how the processor moves through the defined libraries to identify a logistics category is shown in Figure 1.

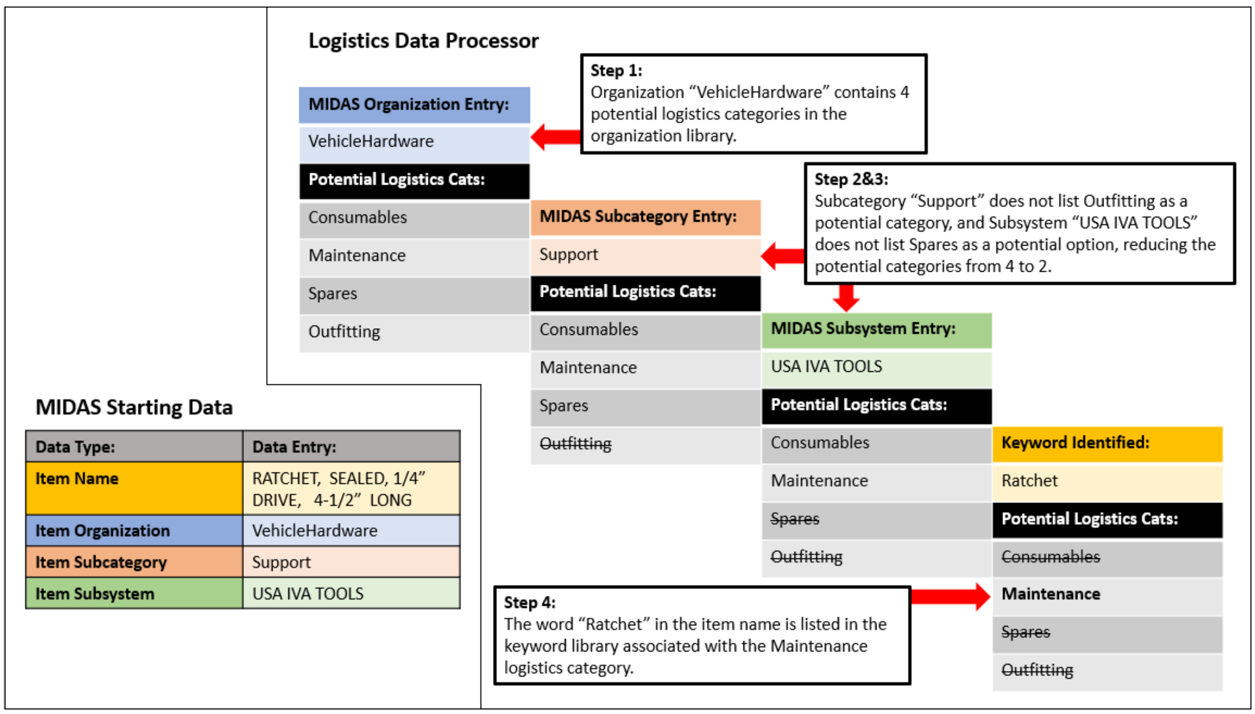

Figure 1. Logistics categorization process for MIDAS data.

B. Crew Time

The main data source for crew activity and crew time data is NASA's Operations and Planning Timeline Integration System (OPTimIS). OPTimIS is a system used by ISS ground crew support and onboard crew members that provides the crew a daily schedule and allows the crew members to enter notes on how the activities went. The data from OPTimIS includes activity name, activity duration, crew members involved, and a brief description of the activity. Starting in 2017, the authors created a data processor that analyzes the raw OPTimIS data to categorize the activities based on the categories outlined in Section II and analyze the time spent on onboard activities.[2] The processor has been updated by the authors and used to provide data for this analysis. A detailed description of how the processor categorizes and analyzes activities from raw OPTimIS data to the defined categories is provided in Stromgren et al.[2]

IV. Results

The results of this paper include the logistics deliveries and crew time on board ISS from over six years of operations, with 79 cargo and crew deliveries to station from October 1, 2017, to December 31, 2023. The deliveries and missions included in the analysis are listed in Table A-1 in the appendix.[4]

A. Logistics Deliveries

Between October 1, 2017, and December 31, 2023, roughly 134 metric tons of logistics were delivered to the ISS. The total mass of the items logged in MIDAS, along with an additional packaging mass margin, is shown in Figure 2. MIDAS only includes packaging that is intended for on-board use and does not include the packaging required to deliver the payloads. Based on recommendations from the ISS Visiting Vehicle Engineering (VVE) team, a packaging mass margin was applied to the MIDAS mass data results. This added margin covers all packaging, including Cargo Transfer Bags (CTBs), foam, and additional wrapping or protection.

The delivered mass of logistics and the breakdown of logistics items delivered shown in Figure 2 were validated through comparisons with previous, similar studies[3] and with official individual launch manifests available in MIDAS.

Although total logistics deliveries and logistics breakdowns are important for understanding roughly what needs to be delivered to support human spaceflight, it is also useful to understand when these logistics were delivered and the missions they were supporting. Figure 3 shows the cumulative logistics mass delivered to ISS by the missions listed in Table A-1[4] and includes the scheduled crew time and crew size on board the ISS during these logistics deliveries. The time period noted as Region A in Figure 3 will be further analyzed in Subsection C.

Each step increase in Figure 3 represents the deliveries to ISS, either crewed or uncrewed, and the mass of logistics that was delivered. Examining Figure 3, there is a visible increase in the rate of consumables

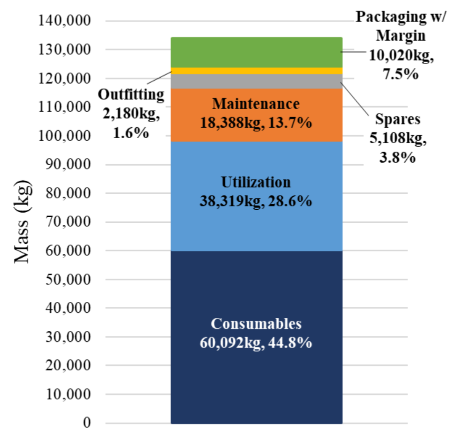

Figure 2. Total Logistics Mass Delivered to ISS from Oct. 1, 2017, to Dec. 31, 2023, with mass and percentage of total mass listed.

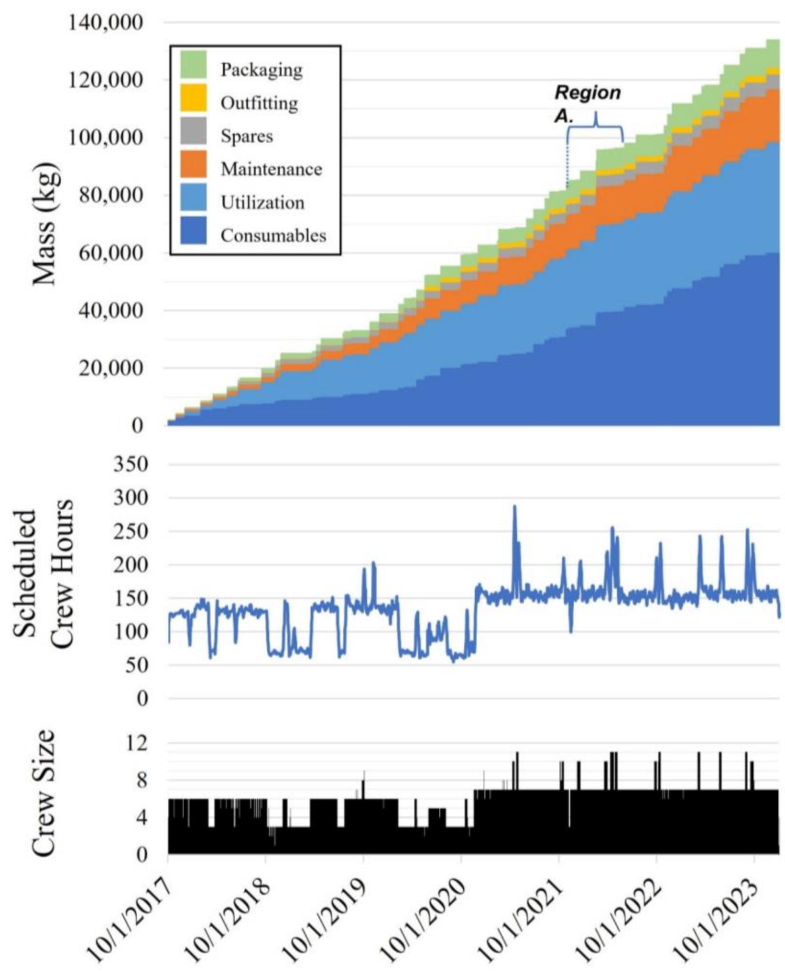

Figure 3. Crew size, scheduled crew time, and delivered logistics mass to ISS from October 1, 2017, to December 31, 2023.

mass being delivered to station beginning around April of 2020. There are several possible factors behind this increase that are being investigated by the authors at the time of this paper. Potential reasons may include preparations for consistent increases in crew size, or the fact that crew launches from the United States returned around this time.

Figure 3 provides an example of the mass required to support human spaceflight over a long duration. However, spaceflight campaigns are not just one long mission, but a series of individual missions and flights that need to be planned early on to reach long-term goals. An important factor of logistics mass delivered during spaceflight campaigns is crew endurance. The length that crew have been (or will be) on board the ISS between cargo resupplies (the horizontal distances between deliveries in Figure 3) affect the mass of logistics deliveries (the vertical step increases in Figure 3), and vice versa. The proximity of the ISS to Earth provides the ability for frequent, relatively cheap resupplies that can be in quick response if needed. Cargo supply missions for crewed missions to the lunar surface and Mars will be significantly more complex and costly. These crewed missions will likely rely on fewer cargo supply missions per crew mission compared to ISS missions. Decreasing the amount of cargo missions for Mars and lunar surface missions will potentially increase the mass of logistics delivered per mission, accounting for possible contingency needs or events during crewed missions.[5]

B. Operation Activities and Crew Time

Crew activities and associated time are scheduled to meet mission goals or in response to events on board the ISS. Some activities, such as those in the non-work category and exercise, follow a strict schedule to safeguard crew health. Many activities in the work category are scheduled in response to crew events that require crew time spent, including traffic and maintenance. Crew time is a finite resource. Any time spent on one activity will reduce the available time to perform all other activities. Mission analysts must balance the time required to complete necessary tasks on station to optimize the time available for all other desired tasks on board. Time spent addressing new or departing vehicles, managing inventory, maintaining vehicle upkeep, or addressing crew health will have a direct impact on the available time for science and utilization activities. Understanding the required crew time to support events such as vehicle traffic or maintenance helps analysts predict the required time on those activities for future missions, as well as the possible available crew time for science and utilization. The following results will analyze the breakdown of required crew time for the different activities on board

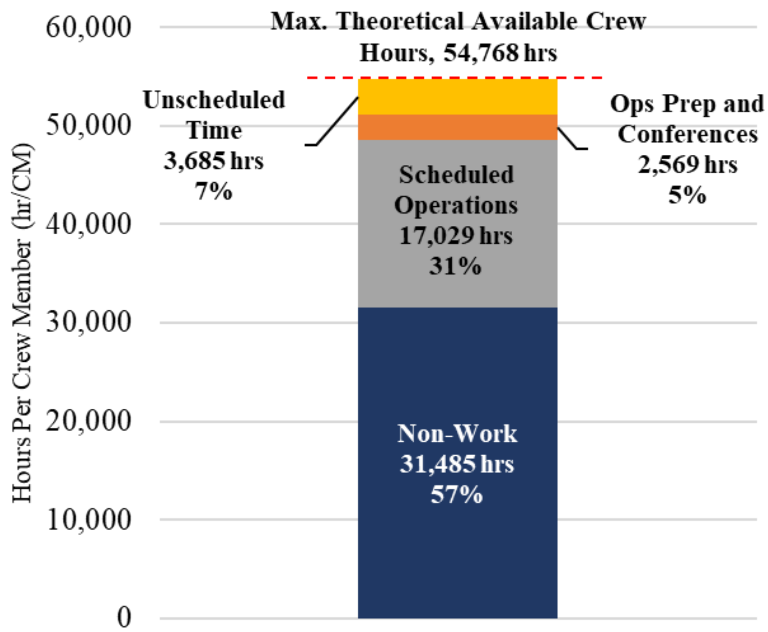

Figure 4. Cumulative crew time on activity categories, normalized per crew member, on ISS from October 1, 2017, to December 31, 2023.

Table 3. ISS guidelines for daily schedule work and non-work activities compared to analyzed OPTimIS data.[6]

Category	ISS Guideline Target Value (Hours per crew member, daily)	OPTimIS Results (Hours per crew member, daily average)	Results Deviation from Guideline
Non-Work	13	13.7	5.4%
Work	8.5	8.4	-1.1%

the ISS during the timeline outlined in Table A-1, and how certain events may affect the required crew time per activity.

Crew on board the ISS follow a consistent schedule for sleep, presleep, postsleep, and meals. The scheduled time for work activities varies between days, but mission operators attempt to keep scheduled work activities under 8.5 hours per day.[6] This leaves a portion of the day unscheduled in OPTimIS, and the crew is able to fill this time how ever they choose. Figure 4 shows the cumulative hours scheduled per crew member over the analyzed time period, with the percentage of total time on station for each activity type.

The crew time results from OPTimIS data shown in Figure 4 reflect the expected distribution of crew activities by category. ISS missions follow guidelines on crew work days, and mission operators try to schedule crew 13 hours daily for personal time along with the work day of 8.5 hours.[6] These guidelines are listed in Table 3, along with the results of the OPTimIS data analysis shown in Figure 4.

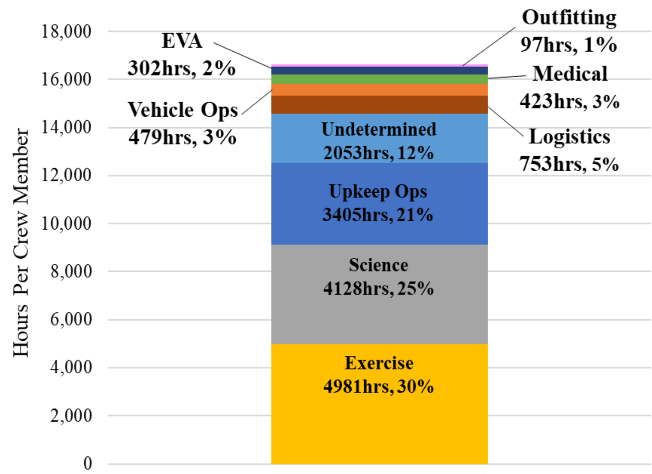

Figure 5. Total scheduled operations hours per crew from Oct 1, 2017, to Dec 1, 2023, with total activity hours and percentage of total scheduled operations crew time.

The increase in scheduled non-work times in the OPTimIS data compared to the ISS guidelines is likely due to crew scheduling their "free time" (non-scheduled personal time) in OPTimIS when it is available. Figure 5 shows scheduled activity time by activity.

Table 4. Average hours per crewmember week for work activities.

	Activity	Weekly Average Per Crewmember (Hours)	Total for Subcategory (Hours)
Scheduled Operations	Exercise	15.3	**39.0**
	Undetermined	6.3	
	Routine Ops	4.5	
	Medical	1.3	
	Maintenance	6.0	
	Training	1.3	
	EVA	0.3	
	Logistics	2.3	
	Traffic	0.3	
	Standup/Closeout	1.2	
	Outfitting	0.3	
Ops Prep and Conferences	Public Relations	1.0	**7.9**
	Conferences	3.3	
	Work Prep	3.3	
	Tag-Ups	0.3	

The activities in the scheduled operations category vary based on mission objectives and events on station. Figure 5 shows the average breakdown of how the activities make up the scheduled operations time. The results shown in Figure 5 reflect a standard crew work day during spaceflight missions. However, it does not reflect how different operations or mission requirements may alter crew workload. Certain events or mission needs may greatly change the crew activity requirements during a mission. Figure 6 shows crew workload, represented by hours per crew member during a week, as the deviation of the work-week crew hours compared to the average weekly workload, listed in Table 4, from October 1, 2017, to December 31, 2023.

There are several high peaks of deviation from the average shown in Figure 6. The six highest increases in crew scheduled workload are all preceded, and sometimes also followed, by incoming or departing vehicles. The highest peaks for scheduled operations (see peaks preceded by deliveries a, b, c, d, and e) are dominated by increases in traffic operations, outfitting, training, and logistics activities. The top peaks for operations prep and conference activities (see peaks preceded by delivery f) are dominated by public relations events and work prep activities. These activities being the drivers behind the sharp increases in workload were expected, as incoming vehicles require immediate action in docking and undocking events, followed by logistics management and preparing new equipment for use. New crew arrivals are expected to receive an increase in training operations and work prep activities early into their mission, and departing crews require training operations for undocking activities. Based on the data in Figure 6, it seems likely that any vehicle transfers (either docked or on surface) for human missions beyond LEO will require increased crew workloads surrounding the events. This reasoning from the data analysis also reflects early timeline concepts for future spaceflight missions beyond LEO previously analyzed, as the conceptual timeline in Lynch et al.[7] predicts increased crew workloads during the first and last several days of a lunar surface mission. However, some questions from this data remain unanswered. For example, why are there sharp increases in workload for some vehicle arrivals, but not all? The authors are continuing the investigation into this question at the time of this paper and hope to find answers as the dataset is further refined and examined.

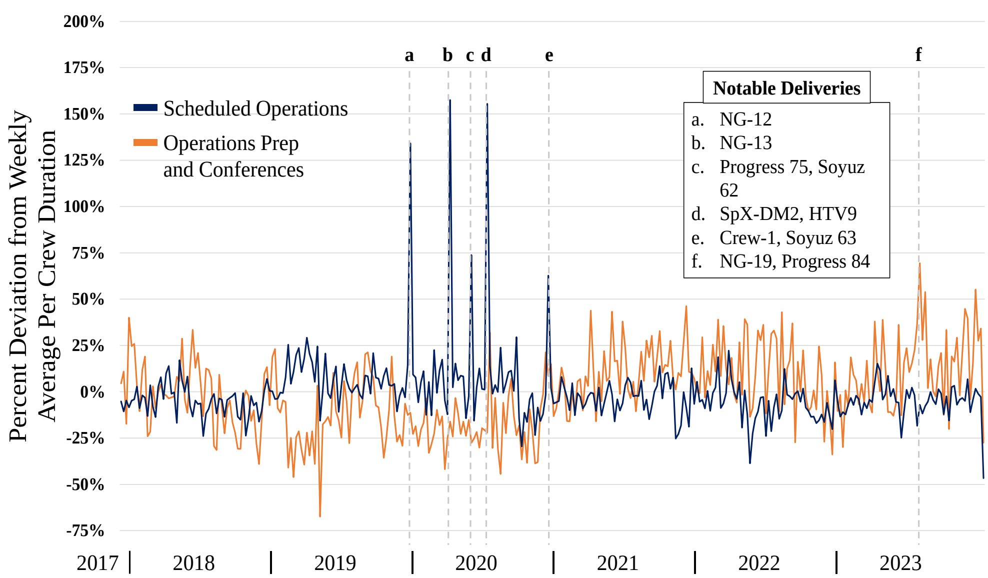

Figure 6. Deviation of the weekly total scheduled operations and operations prep and conferences hours per crew member from the weekly average from Oct 1, 2017, to Dec 31, 2023.

C. Detailed Analysis of October 2021 to June 2022

The authors examined the deliveries between October 14, 2021, and June 14, 2022 (see Region A in Figure 3) and the missions around the deliveries—including mission goals and duration—to understand the mass and type of logistics being supplied as well as the delivery frequency. This time period was selected because of the variations in delivery types, varying crew endurances, and changes in crew size. Figure 7 shows a zoomed in look at the mass requirements of this time period. Region A in Figure 3 shows an extended period of light to no cargo deliveries, followed by a large increase in delivered mass in a short period of time, followed again by an extended duration of light to no cargo deliveries. In late October 2021, Progress 79 delivered roughly 3.1 metric tons to station. There were then two crew arrivals to station, Crew-3 with four crew members and Soyuz 66 with three crew members. These crew arrivals took place on November 11 and December 8, 2021, respectively, and there was no additional cargo delivery until December 22, 2021, with the arrival of SpX-24 with 3.1 metric tons of cargo, of which 2.8 tons were consumables. Over the nine-week period between the Progress 79 and SpX-24 deliveries, seven crew members were on board station with no main cargo delivery (Crew-3 and Soyuz 66 arrived with roughly 440 kg and 200 kg of logistics, respectively). Following the SpX-24 delivery, crew remained on board without a cargo delivery for nearly two more months, until the arrival of Progress 80 on February 17, 2022, with roughly 3.4 metric tons of logistics, with 3.1 tons of the delivery being consumables. Several days after the arrival of Progress 80, NG-17 arrived with 1.5 tons of consumables, 1 ton of maintenance items, 850 kg of utilization equipment, and roughly 540 kg of additional items and packaging margin for a total of nearly 3.9 tons of logistics. That is a total logistics delivery of 7.3 tons in only five days. These large deliveries of logistics in short succession are likely tied to the extended time crew went without logistics resupply, and to the need to deliver the supplies for the subsequent missions. Shortly after the arrival of NG-17, on March 18, 2022, Soyuz 67 arrived, and the amount of crew increased to 10. Ten crew members remained on station for nearly two weeks, when three members departed on March 31. However, it was only 10 days until the tourist arrival of Ax-1 with four more crew members. These four private astronauts remained on station for two weeks before departing, bringing the size of the crew back to seven. This lasted only five days, however, as the arrival of Crew-4 happened on April 28, bringing the size of the crew back up to 11 for eight days, when four crew members departed. The short duration between these crew arrivals caused the ISS, and ISS logistics, to support 10 or 11 crew members for the vast majority of two months instead of the normal seven-member crew.[4] A large amount of goods was required to be delivered to support this increased strain, especially following a long duration of no crew resupply.

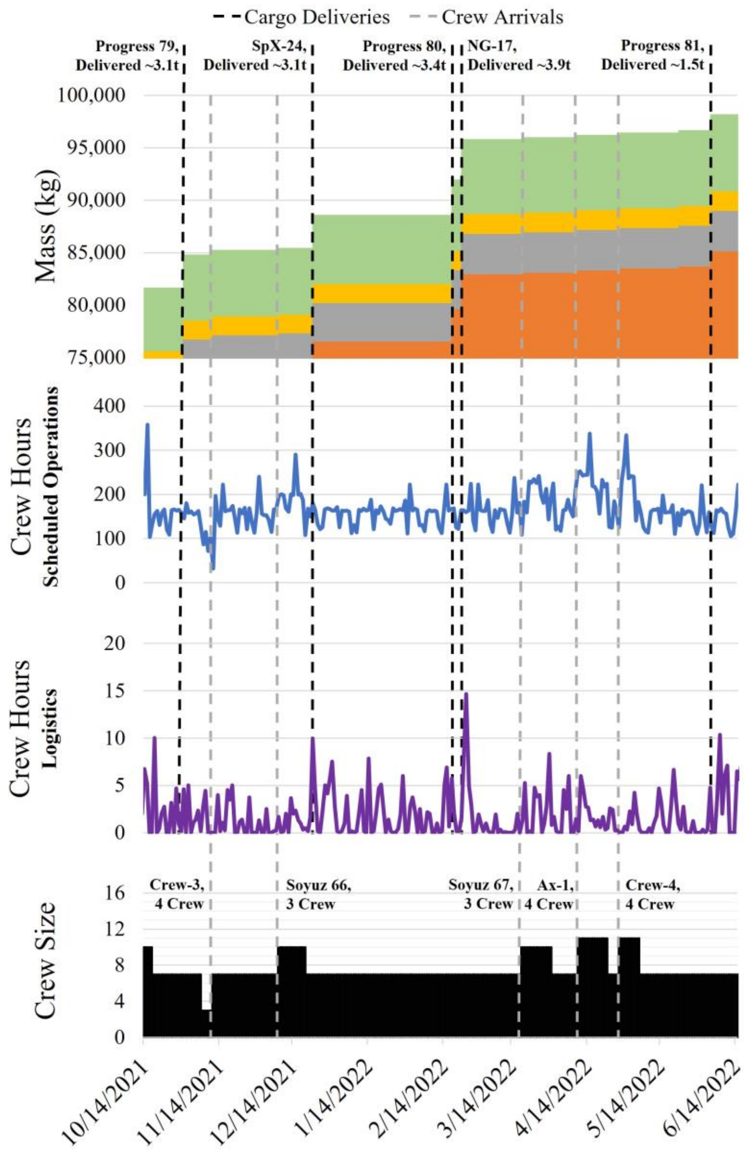

Figure 7. Cumulative logistics mass delivered (top), crew time for scheduled operations (second from top) and logistics (second from bottom) activities, and crew size (bottom) to and on board the ISS from October 14, 2021, to June 14, 2022.

The crew time needs reflected in Figure 7 reveal interesting patterns in the relationship of logistics deliveries and required crew time. The most massive cargo delivery during this timeline, NG-17, was followed immediately by the largest peak of required crew time dedicated to logistics. The peak in crew time on logistics following NG-17 was also likely caused by the delivery of Progress 80 just prior to NG-17 for a combined logistics delivery of 7.3 tons in only four days. This correlation of large logistics deliveries and increased crew time dedicated to logistics is expected.

However, cargo deliveries do not consistently create spikes in logistics crew time. For example, the Progress 79 and Progress 81 deliveries are not immediately followed or preceded by spikes in crew time on logistics. The reason for this may be a result of the ISS and visiting vehicle's architecture. Visiting vehicles can remain docked on the ISS for extended periods of time, acting as a large storage closet. Because of this, crew members do not need to immediately transfer all the required logistics and trash to and from the visiting vehicle. Additionally, the docked vehicle provides more stowage volume for logistics, which decreases the time needed to transfer logistics around station. But as shown by the sharp increase in required crew time on logistics following NG-17, the added stowage space from a docked module does not completely eliminate increases in crew time. Progress 80 and NG-17 were months after any crew or cargo delivery, and the crew on board likely went through a substantial amount of consumables and equipment that needed to be restocked or outfitted as soon as possible. For future missions beyond LEO, this increase in required logistics crew time following resupply may be larger, and therefore it is important to conduct rigorous logistics and crew time assessments to inform system development.

Patterns similar to the one detailed in the paragraph above and highlighted in Figure 7 are repeated throughout the timeline analyzed. The patterns in the data provide an overview of how human spaceflight campaigns are currently executed, with multiple launches and deliveries supporting a number of missions. What is not highlighted in the data, however, is the planning process behind these deliveries and missions. Understanding consumable consumption rates, system failure rates, atmospheric needs, and many other factors that go into mission support is vital for proper mission planning. Supportability and logistics analysis can help decision-makers understand the relationship between system architecture, mission architecture, risk, mass, and crew time. Supportability analysis techniques and concepts are described further by Vega et al.[8] and Piontek et al.[9] Launching vehicles, people, and cargo into space is not a simple and quick process; it is a long process with a large amount of precise planning. When designing and planning for a mission, the further along the design process is, the harder it is to make changes. Once a campaign starts, errors in planning cannot be easily and immediately fixed. The cargo needed to support each mission in the campaign is affected by the cargo needs and goals of the previous missions, and inversely the cargo and goals of the first mission can be affected by the cargo needs and goals of a later mission.

V. Discussion

By connecting the required logistics and crew time needs to the ISS duration, crew size, and operations they were supporting, analysts can predict the requirements for desired mission durations, crew sizes, and operational goals for future missions. These results provide a reference to analysts when designing new missions, providing insight into the potential required deliveries and reasonable utilization goals. To use the data from ISS for future missions however, the differences between ISS missions and NASA's future missions beyond LEO must be known. Human missions beyond LEO can be generalized into two types: deep space transit missions and surface missions.

Transit missions are orbital missions during which the crew remain in a microgravity setting. The major differences between these missions and ISS missions, from a crew time and logistics perspective, include increased durations, decreased abort availability, decreased resupply availability—if resupply is even possible—and increased uncertainties in human health and performance, such as significantly increased radiation effects.[10] These differences will likely lead to increased delivered mass of logistics to mitigate the risk of not having rapidly available resupply or abort and could also see crew time effects due to system or procedure changes to mitigate health risks, among many other possible variations from ISS logistics and crew time data.[10]

Surface missions, including both the lunar and Mars surface, are shorter duration missions than ISS missions. Surface missions, like transit missions, will see decreased abort and resupply availability as well as increased risks to human health and performance, including radiation risks. Additionally, surface missions will include new factors of dust and low-light environments. Systems will have to be designed to survive these new conditions and could see both increases in logistics mass to support the systems and increases in crew time dedicated to keeping the systems operational. Unlike the ISS, these systems will also have to survive extended uncrewed durations. Because of this, certain systems may rely on redundant subsystems and components, increasing the mass of the systems and the spares required. The increased gravity on surface missions may have an affect on crew exercise and EVA requirements, as the crew are under more strenuous conditions. Factors such as the ones mentioned are used as a bridge to connect the data gathered on ISS to the requirements and likely needs to support future missions beyond LEO.

This paper represents the results of a study of the large datasets containing ISS operational data mentioned earlier in Section II. Although the results were verified through comparisons with existing sources, there are still opportunities for improvement to the analysis tools used here. The data processors used in this analysis are still in development, and one of the challenges of this study is handling the size and complexity of the logistics and crew time datasets. The authors plan to continue refining the tools for analysis and analyzing the data shown in this paper to provide further reference data for spaceflight mission analysts.

VI. Conclusion

The ISS is one of the most valuable resources currently in operation that can provide high-fidelity flight data for human spaceflight operations and inform planning for future missions. With over 20 years of operations data, there are vast lessons learned from the ISS that can be applied to future Artemis and Mars spaceflight campaigns. The scientific and exploration goals for those campaigns, however, are limited by the cargo required to support the missions and the finite time the crew has to achieve the goals. The study outlined in this paper shows historical logistics requirements for supporting human spaceflight, as well as analyzes historical crew time during missions to put reasonable expectations on what is possible for future missions. This study, along with several others across NASA, aim to learn as much from the ISS as possible in an effort to utilize the information to further expand humanity's reach in space.

Appendix

Table A-1 Logistics and crew deliveries to ISS between Oct 1, 2017, and Dec 31, 2023.[4] Crewed flights are bolded.

Launch ID	Launch Name	Launch Date	Docking Date	Launch ID	Launch Name	Launch Date	Docking Date
197	Progress 68	10/14/2017	10/16/2017	237	Progress 77	2/15/2021	2/17/2021
198	OA-8	11/17/2017	11/14/2017	238	NG-15	2/20/2021	2/22/2021
199	SpX-13	12/15/2017	12/17/2017	**239**	**Soyuz 64**	**4/9/2021**	**4/9/2021**
200	**Soyuz 53**	**12/17/2017**	**12/19/2017**	**240**	**Crew-2**	**4/23/2021**	**4/24/2021**
201	Progress 69	2/13/2018	2/15/2018	241	SpX-22	6/3/2021	6/5/2021
202	**Soyuz 54**	**3/21/2018**	**3/23/2018**	242	Progress 78	6/29/2021	7/2/2021
203	SpX-14	4/2/2018	4/2/2018	243	Nauka	7/21/2021	7/29/2021
204	OA-9	5/21/2018	5/24/2018	244	NG-16	8/10/2021	8/12/2021
205	**Soyuz 55**	**6/6/2018**	**6/8/2018**	245	SpX-23	8/29/2021	8/30/2021
206	SpX-15	6/29/2018	7/2/2018	**246**	**Soyuz 65**	**10/5/2021**	**10/5/2021**
207	Progress 70	7/9/2018	7/10/2018	247	Progress 79	10/28/2021	10/30/2021
208	HTV7	9/22/2018	9/27/2018	**248**	**Crew-3**	**11/11/2021**	**11/11/2021**
209	Progress 71	11/16/2018	11/18/2018	249	Progress M-UM*	11/24/2021	11/26/2021
210	NG-10	11/17/2018	11/19/2018	**250**	**Soyuz 66**	**12/8/2021**	**12/8/2021**
211	**Soyuz 57**	**12/3/2018**	**12/3/2018**	251	SpX-24	12/21/2021	12/22/2021
212	SpX-16	12/5/2018	12/8/2018	252	Progress 80	2/15/2022	2/17/2022
213	SpX-DM1	3/2/2019	3/3/2019	253	NG-17	2/19/2022	2/21/2022
214	**Soyuz 58**	**3/14/2019**	**3/15/2019**	**254**	**Soyuz 67**	**3/18/2022**	**3/18/2022**
215	Progress 72	4/4/2019	4/4/2019	255	Ax-1	4/8/2022	4/9/2022
216	NG-11	4/17/2019	4/19/2019	**256**	**Crew-4**	**4/27/2022**	**4/27/2022**
217	SpX-17	5/4/2019	5/6/2019	257	Boe-OFT2	5/19/2022	5/21/2022
218	**Soyuz 59**	**7/20/2019**	**7/20/2019**	258	Progress 81	6/3/2022	6/3/2022
219	SpX-18	7/25/2019	7/27/2019	259	SpX-25	7/15/2022	7/16/2022
220	Progress 73	7/31/2019	7/31/2019	**260**	**Soyuz 68**	**9/21/2022**	**9/21/2022**
221	**Soyuz 60**	**8/22/2019**	**8/27/2019**	**261**	**Crew-5**	**10/5/2022**	**10/6/2022**
222	HTV8	9/24/2019	9/28/2019	262	Progress 82	10/26/2022	10/28/2022
223	NG-12	11/2/2019	11/4/2019	263	NG-18	11/7/2022	11/9/2022
224	SpX-19	12/5/2019	12/8/2019	264	SpX-26	11/26/2022	11/27/2022
225	Progress 74	12/6/2019	12/9/2019	265	Progress 83	2/9/2023	2/11/2023
226	NG-13	2/15/2020	2/18/2020	**266**	**Crew-6**	**3/2/2023**	**3/3/2023**
227	SpX-20	3/7/2020	3/9/2020	267	SpX-27	3/15/2023	3/16/2023
228	**Soyuz 62**	**4/9/2020**	**4/9/2020**	**268**	**Soyuz 69**	**3/28/2023**	**3/28/2023**
229	Progress 75	4/25/2020	4/25/2020	269	Ax-2	5/21/2023	5/22/2023
230	HTV9	5/20/2020	5/25/2020	270	Progress 84	5/24/2023	5/24/2023
231	SpX-Demo2	5/30/2020	5/31/2020	271	SpX-28	6/5/2023	6/6/2023
232	Progress 76	7/23/2020	7/23/2020	272	NG-19	8/2/2023	8/4/2023
233	NG-14	10/3/2020	10/5/2020	273	Progress 85	8/23/2023	8/25/2023
234	**Soyuz 63**	**10/14/2020**	**10/14/2020**	**274**	**Crew-7**	**8/26/2023**	**8/27/2023**
235	**Crew-1**	**11/16/2020**	**11/17/2020**	275	SpX-29	11/10/2023	11/11/2023
236	SpX-21	12/6/2020	12/7/2020				

**Progress M-UM delivered 0kg of logistics mass.*

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