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Logistics Lessons Learned in NASA Space Flight

William A. (Andy) Evans, United Space Alliance
Prof. Olivier de Weck, Massachusetts Institute of Technology
Deanna Laufer, Massachusetts Institute of Technology
Sarah Shull, Massachusetts Institute of Technology
Kennedy Space Center, Florida

May 2006

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National Aeronautics and
Space Administration

Kennedy Space Center
Kennedy Space Center, FL 32899-0001

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Executive Summary

The Vision for Space Exploration sets out a number of goals, involving both strategic and tactical objectives. These include returning the Space Shuttle to flight, completing the International Space Station, and conducting human expeditions to the Moon by 2020. Each of these goals has profound logistics implications. In the consideration of these objectives, a need for a study on NASA logistics lessons learned was recognized. The study endeavors to identify both needs for space exploration and challenges in the development of past logistics architectures, as well as in the design of space systems. This study may also be appropriately applied as guidance in the development of an integrated logistics architecture for future human missions to the Moon and Mars.

This report first summarizes current logistics practices for the Space Shuttle Program (SSP) and the International Space Station (ISS) and examines the practices of manifesting, stowage, inventory tracking, waste disposal, and return logistics. The key findings of this examination are that while the current practices do have many positive aspects, there are also several shortcomings. These shortcomings include a high-level of excess complexity, redundancy of information/lack of a common database, and a large human-in-the-loop component.

Later sections of this report describe the methodology and results of our work to systematically gather logistics lessons learned from past and current human spaceflight programs as well as validating these lessons through a survey of the opinions of current space logisticians. To consider the perspectives on logistics lessons, we searched several sources within NASA, including organizations with direct and indirect connections with the system flow in mission planning. We utilized crew debriefs, the John Commonsense lessons repository for the JSC Mission Operations Directorate, and the Skylab Lessons Learned. Additionally, we searched the public version of the Lessons Learned Information System (LLIS) and verified that we received the same result using the internal version of LLIS for our logistics lesson searches.

In conducting the research, information from multiple databases was consolidated into a single spreadsheet of 300 lessons learned. Keywords were applied for the purpose of sorting and evaluation. Once the lessons had been compiled, an analysis of the resulting data was performed, first sorting it by keyword, then finding duplication and root cause, and finally sorting by root cause. The data was then distilled into the top 7 lessons learned across programs, centers, and activities.

The Top 7 Lessons Learned

1. Resulting problems from lack of stowage specification may include growing time demands for the crew, loss of accountability, loss of access to operational space, limits to housekeeping, weakened morale, and an increased requirement for resupply. Therefore, include **stowage requirements** (volume, mass, reconfigurability, etc.) in the design specification.

2. A **common logistics/inventory system**, shared by multiple organizations would decrease the problem of differing values for like items across systems.

3. **Packing lists and manifests** do not make good manual accounting systems. Parent-child relationships are fluid and need to be intuitively handled by a system updated by the movement of both parents and children.

4. **Commonality** is a prime consideration for all vehicles, systems, components, and software in order to minimize training requirements, optimize maintainability, reduce development and sparing costs, and increase operational flexibility.

5. **Design for maintenance** is a primary consideration in reducing the logistics footprint. An optimization is preferable, taking into account tools, time, packaging, stowage, and lifecycle cost.

6. **Plan for and apply standards** to system development. A simple example of this is standard and metric tools. In most cases, where there are multiple standards, there is an interface required, and the interface then requires support.

7. Include **return logistics** requirements in the design specification. Understand and model packaging requirements, pressurization, and reparability/disposability for the return or destructive reentry of items ahead of time.

A Space Logistics Community Survey was developed by integrating the top 7 lessons learned into a 10-part questionnaire. Most questions asked the respondent to rate his/her level of observance of each issue as well as his/her recommendation of each. The final survey analysis is based on a sample of 35 responses from members of NASA, academia, the DoD, and space-affiliated industry.

It was found that virtually all areas surveyed were highly recommended for implementation in current practices. Thus, the survey validated that the top 7 lessons learned are of considerable importance to all participants surveyed, whether from NASA, the aerospace industry, or other industries represented. The survey results also highlighted several weaknesses in current logistics practices. There was a notable need and gap in areas where the observed practice did not meet the recommendation levels. Specifically, the three areas requiring most attention are use of *commonality in systems, inventory management, and design for maintenance*. While some of these may be areas of current mitigation, as exemplified in a separate survey question, some may be areas where there is less ongoing development. In addition to the results of the survey, the method of analysis used revealed that a standard regimen of reviewing lessons learned, consolidating them, and looking for root causes would probably allow broader use of the lessons in new developments.

The conclusion of this report offers recommendations that we believe will help NASA to ensure that logistics is at the forefront of consideration for the Constellation Program and beyond, potentially leading to a substantial cost savings in operations.

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Acknowledgements

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“Strategy and tactics provide the scheme for the conduct of military operations; logistics the means therefore.”

Lieutenant Colonel George C. Thorpe, USMC

“More than any other, Antarctic science is dependant on logistics, on the ability to place and maintain a scientist and his equipment in the right place at the right time. Expeditions to Antarctica up to 1925 depended on techniques of transport, communication, survival, which remained largely unchanged for 100 years….after 1925 the development of mechanized transport, the airplane, radio and technology based on better understanding of human physiology, were to make access to the Antarctic, travel within it and survival in its hostile environment, much less difficult.”

Beck, P.J., The International Politics of Antarctica, London, Croom Helm Inc., 1986, p.131

1 Study Objective

The Vision for Space Exploration [2] sets out a number of goals as strategic and tactical objectives. Many of these goals, such as the ones listed below, have profound logistics implications:

Space Shuttle

- Return the Space Shuttle to flight as soon as it is practical, based on the recommendations of the Columbia Accident Investigation Board [3]
- Focus use of the Space Shuttle on completing assembly of the International Space Station
- Retire the Space Shuttle as soon as assembly of the International Space Station is complete

International Space Station

- Complete assembly of the International Space Station, including the U.S. components that support U.S. space exploration goals and those provided by foreign partners
- Focus U.S. research and use of the International Space Station on supporting space exploration goals, with emphasis on understanding how the space environment affects astronaut health and capabilities
- Conduct International Space Station activities in a manner consistent with U.S. obligations contained in the agreements between the United States and other partners in the International Space Station [4]

The Moon

- Undertake lunar exploration activities to enable sustained human and robotic exploration of Mars and more distant destinations in the solar system
- Starting no later than 2008, initiate a series of robotic missions to the Moon to prepare for and support future human exploration activities
- Conduct the first extended human expedition to the lunar surface as early as 2015, but no later than 2020
- Use lunar exploration activities to further science and develop and test new approaches, technologies, and systems, including use of lunar and other space resources, to support sustained human space exploration to Mars and other destinations

At the inception of the Exploration Systems Research and Technology study entitled *Interplanetary Supply Chain Management and Logistics Architectures [5]*, the investigators determined that there should be a set of studies on terrestrial analogs for space exploration. The decision to add a study on NASA logistics lessons learned was based on data needs for space exploration, challenges encountered in the development of a logistics architecture, as well as in the design of space systems, and a need for guidance in the development of a logistics architecture for future missions to the Moon and Mars (Figure 1).

The study, assigned to United Space Alliance LLC in Houston, TX, was to review as many sources of Logistics Lessons Learned as were available, and to attempt to draw some conclusions about the current state of NASA's logistics architecture and any challenges to developing an interplanetary supply chain.

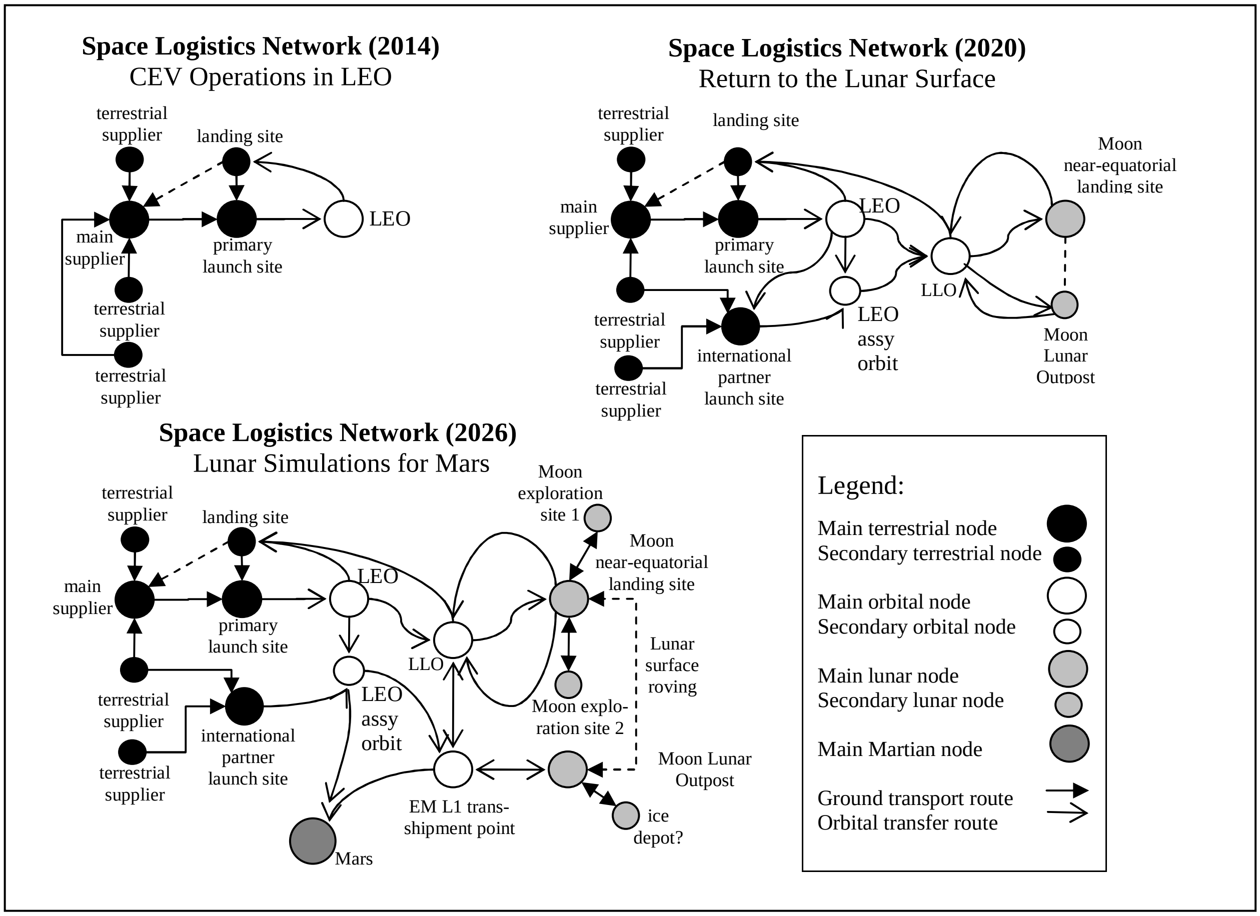


Figure 1: The growing complexity of the NASA logistics network architecture

We believe it important to document and learn from the past. As part of this task we investigated lessons learned from both ISS and Shuttle space logistics. Our team had and gained significant practical experience to distill these lessons learned, and to bring supporting data to the models and simulations in support of future exploration logistics.

A result of this study is significant insight into logistics lessons learned within NASA. This analysis provides both role-based and program-based perspectives over the programs and activities studied. In performing the study, we also developed a methodology for looking across programs for logistics lessons, which may be applied to future research.

2 Current Practices for Space Shuttle and ISS Logistics

To ground this study in current practices, we include a brief overview of logistics procedures for both the Space Shuttle Program (SSP) and International Space Station (ISS). Among the logistics practices examined are manifesting, stowage, inventory tracking, waste disposal, and return logistics. These topics are among those that served as the basis for extracting the lessons learned and lessons not learned from the programs examined.

2.1 ISS Cargo Lifecycle

Since the inception of the ISS in 1998, much of NASA efforts in human space flight have been centered on assembling and supplying the ISS. As such, we have focused our discussion of current practices on the complex task of getting cargo from Earth to the ISS and the management of this cargo on-orbit.

2.1.1 Manifesting for ISS

The process of sending an item to ISS or returning an item from ISS begins with the submission of a manifest request (MR). Any hardware owner or responsible group may submit an MR. MRs are reviewed at the weekly Manifest Working Group (MWG) meeting. Once reviewed by the MWG, the MR is forwarded to either the affected launch team or increment team for their review and approval/disapproval. If the MR is approved, the request will appear on the next manifest change request (CR) with all other approved MRs. The CR receives a community wide review and is evaluated based on cost, delivery schedule, certification, stowage space on launch/return vehicle, stowage space on ISS, power requirements, etc. Figure 2 below illustrates this process.

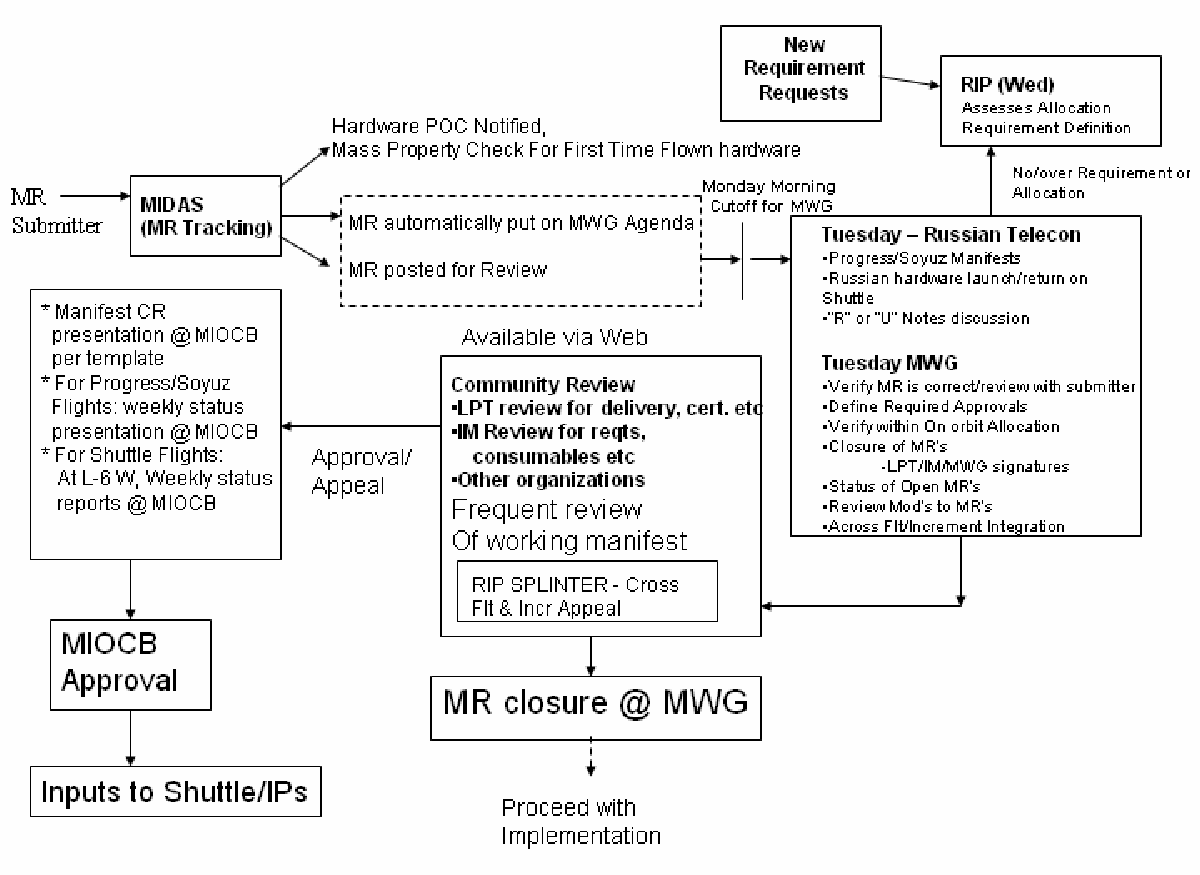


Figure 2: ISS Manifesting Flowchart

2.1.2 Cargo Review Cycle

A simplified overview of the ISS cargo review cycle is shown in Figure 3 below. ISS cargo manifesting is duplicative in many ways, since the vehicle that will transport it is unknown at the time the cargo is identified and subject to change based upon availability of the transportation system. Currently, the available launch vehicles include the Russian Progress, the U.S. Space Shuttle, and to some extent the Russian Soyuz. In the next few years, the Japanese Aerospace Exploration Agency (JAXA) HII Transfer Vehicle (HTV) and European Space Agency (ESA)'s Automated Transfer Vehicle (ATV) [6] will also be viable launch options.

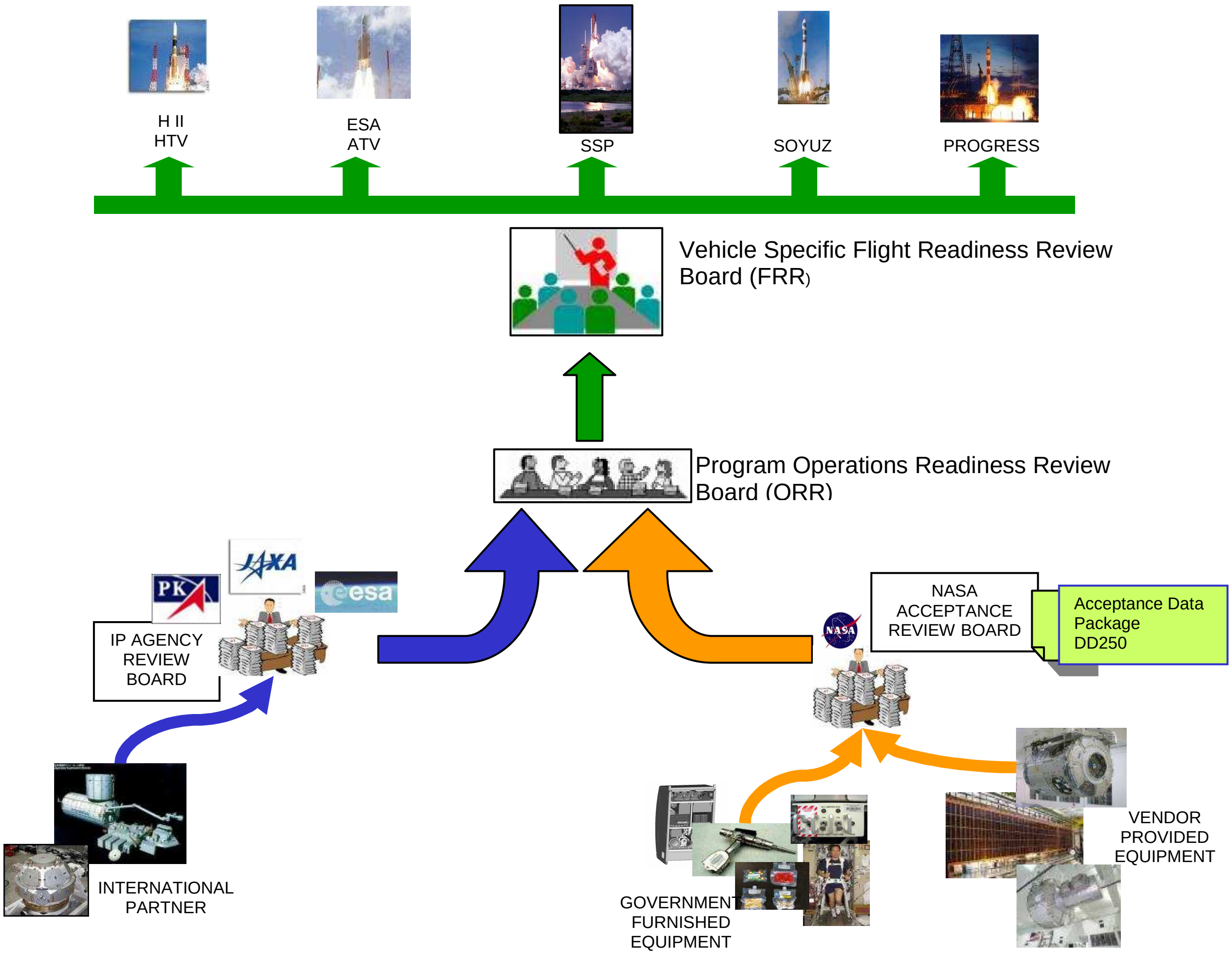


Figure 3: Simplified ISS Cargo Review Cycle

2.2 Space Shuttle Logistics

Once a cargo item passes through the review cycle depicted in Figures 2 and 3 above and is designated to launch on the Space Shuttle, the cargo is then categorized as a Shuttle payload. Shuttle payloads fall into three categories, primary, secondary, and middeck. A definition of each follows:

- **Primary:** A primary payload justifies a Shuttle mission, either alone or in combination with other payloads, and meets the criteria of the Shuttle use policy set forth in NMI 8610.12B, *Policy for Obtaining Office of Space Flight Provided/Arranged Space Transportation Service for NASA and NASA-Related Payloads*, as determined by the NASA Flight Assignment Board and approved by the NASA Administrator. A primary payload typically defines the critical path of the integration process, including KSC processing, flight design and mission operations preparation, and postflight processing and data reduction.

- **Secondary payload**: In general, a secondary payload does not define the critical path of the integration process, but has requirements that use significant SSP resources. However, a combination of secondary payloads may represent justification for a Shuttle mission in the same sense as a primary payload. A secondary payload, or combination of secondary payloads, which defines the critical path of the integration process, including KSC processing, flight design and mission operations preparation, and postflight processing and data reduction will be treated as a primary payload for manifesting purposes.

- **Middeck:** A middeck payload is a payload which uses the accommodations in the Shuttle middeck (as defined in NSTS 21000-SIP-MDK and/or NSTS 21000-IDDMDK). In general, a middeck payload does not define the critical path of the integration process, but has requirements that use significant SSP resources. A picture of the Shuttle middeck lockers is shown in Figure 4.

Figure 4: Shuttle Middeck Lockers

Once the proper payload designation is made for all cargo on that Shuttle mission, a Shuttle manifest change request (CR) can be developed for the vehicle. The Shuttle payload integration flow, shown in Figure 5, illustrates this process.

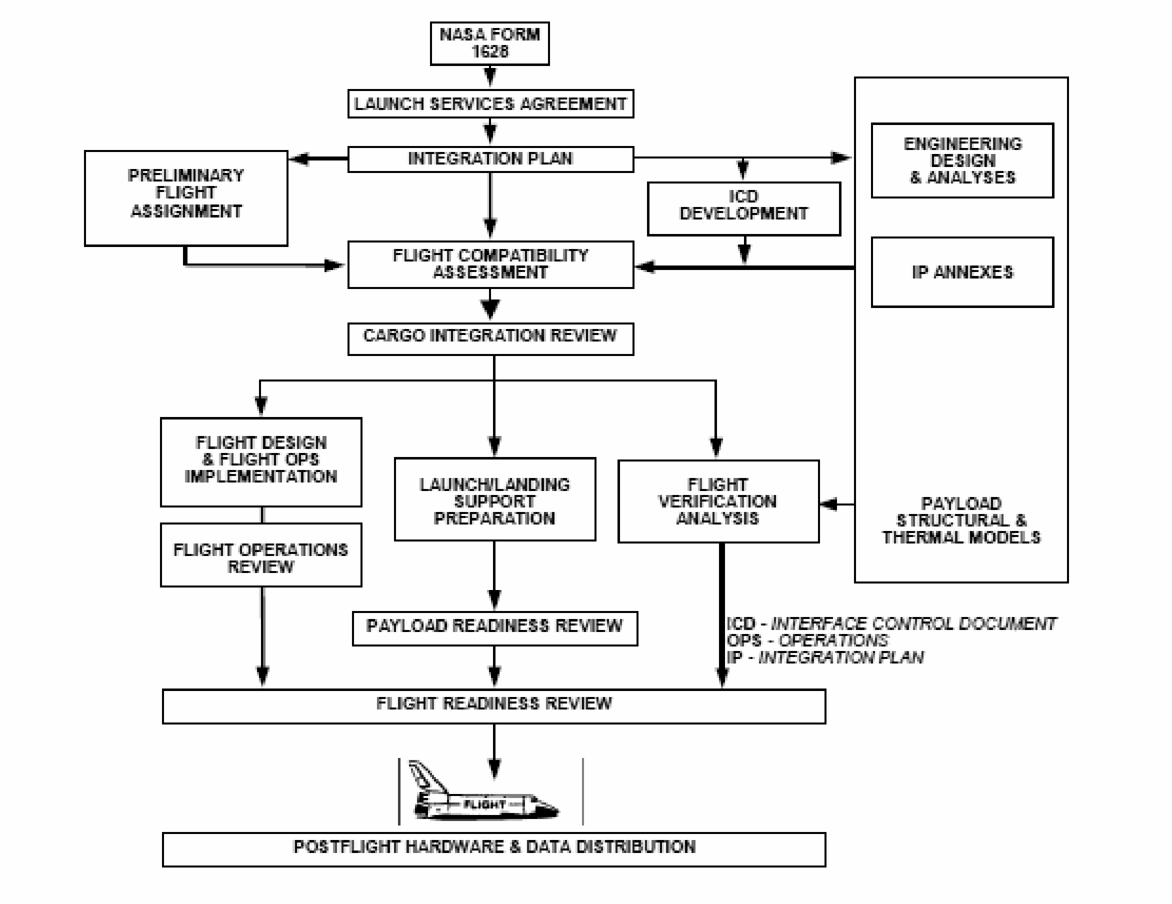


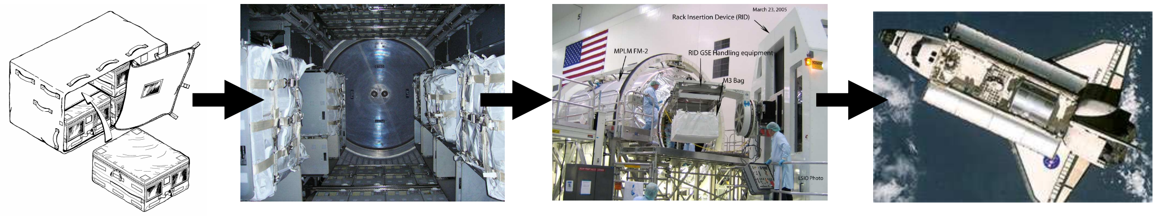
Figure 5: Shuttle Payload Integration Process

2.3 ISS Logistics

2.3.1 Stowage Planning for ISS Resupply

The Shuttle stowage group reviews the manifest CRs and determines the launch and return stowage configurations for the Multi-Purpose Logistics Module (MPLM), middeck crew compartment, and payload bay. Overview drawings are produced to show how bags and items are packed into the U.S. launch vehicles. Detailed drawings are also produced to show the internal configuration of compartments and bags. Ascent packing configurations are driven more by hardware delivery schedules and launch requirements (packing material) than by the on-orbit use and stowage of an item. When possible, ascent packing materials are returned on the launch vehicle so that the impact on ISS stowage space is minimized.

The nested complexity of cargo in the Space Shuttle, ISS, MPLM, etc. is one of the major challenges in current space inventory management practices. Figure 6 below illustrates this complexity. The components of Figure 6 are explained in the sections that follow.



Supply Items in Bags

Bags in MPLM Racks

MPLM Cargo Integration

MPLM in Shuttle

Figure 6: Nested Complexity of Shuttle Cargo in an MPLM

2.3.2 Carriers

The Shuttle middeck and MPLM provide accommodations for internal cargo. The payload bay provides stowage accommodations for external (unpressurized) cargo.

The Shuttle middeck includes lockers and floor/ceiling bags. Each middeck locker has dimensions of about 20”x18”x10”. There are two types of floor/ceiling bags; one type holds 5 middeck locker equivalents (MLE) and the other holds 10 MLEs. The lockers and floor/ceiling bags can be packed with cargo transfer bags (CTBs), mesh bags, or loose hardware. When necessary, the hardware items are packed in foam cushions. Since the relatively small size of the middeck lockers restricts the size of the items that can be launched, the floor and ceiling bags provide the capability to launch and return oversized items.

The MPLM has 16 rack bays. Each rack bay can be configured to carry a Resupply Stowage Platform, a Resupply Stowage Rack, an Express Transport Rack, or be left empty.

2.3.3 Containers

2.3.3.1 Racks

A Resupply Stowage Platform (RSP) is a flat plate that can pivot at the bottom. Large M-bags are mounted on the front and back sides of the RSP. Cargo can be packed loosely into the M-bags or packed into CTBs before being stowed in the M-bags. RSPs are only flown in the MPLM and do not transfer to ISS. RSPs provide the capability to launch and return oversized items in the MPLM.

A Resupply Stowage Rack is a metal rack with locker compartments of various sizes. Hardware can either be packed loosely into the compartments or within CTBs that are then placed in the compartments. RSRs are flown in the MPLM and can be transferred and installed on ISS as needed. RSRs provide a limited capability to launch and return large items.

An Express Transport Rack (ETR) is a metal rack that is primarily used to transfer payload cargo to ISS. ETRs are flown in the MPLM and do not transfer to ISS. An ETR has accommodations for locker mounted payloads and International Sub-rack Interface Standard (ISIS) drawers that interface with the Express Racks on ISS.

On ISS, there are 4 types of racks; Express racks, Zero-G stowage racks, RSRs and system racks. An Express Rack is a metal rack installed on ISS and designed to accommodate payloads. Express racks usually consist of 8 locker compartments equivalent to a middeck locker and 3 drawers. The locker compartments can be used for powered payloads or passive stowage. The drawers are used for passive stowage.

Zero-G Stowage Racks (ZSRs) are fabric racks that are used on ISS to provide stowage accommodations. The internal compartments of the ZSRs are reconfigurable so that different size cargo can be stowed.

System racks are metal racks that have been outfitted with particular system hardware. When the entire rack space is not needed for the system components, lockers are built into the rack to provide additional stowage. Most of these lockers are the same size as RSR lockers.

2.3.3.2 Bags

Cargo transfer bags (CTBs) are the primary packing container for ISS. CTBs are available in four sizes to provide maximum flexibility when packing hardware. The single CTB was designed to fit inside a middeck locker. Half size CTBs (half the size of a middeck locker), double CTBs, and triple CTBs are also available. CTBs were primarily designed to modularly interface with the ZSRs, although the half and single CTBs are also compatible with the Express rack lockers and most locations in RSRs and system racks.

There are three sizes of M-bags; M-01 (6 CTBE), M-02 (4 CTBE), and M-03 (10 CTBE). Their capacity is defined in cargo transfer bag equivalents (CTBE). A single CTB is 1 CTBE, which corresponds to a volume of 1.86 cubic feet.

2.3.4 Transfer Operations

Transfer Operations describes the transfer of cargo between the Shuttle and ISS. The transfer team uses the approved manifest CRs and the ascent/descent stowage drawings to develop the transfer list that the crew uses. The transfer list is an Excel spreadsheet that is printed in hardcopy for the crew to use during the Shuttle flight. Changes to the transfer list are up-linked either as pen and ink changes that the crew handwrites into their transfer book or as an electronic file that the crew can print on-orbit. At the end of each mission day, the crew reports through a voice call-down the transfers that were completed that day. The transfer team updates an electronic copy of the transfer list and distributes the updates to others in the control center.

A similar process is followed for the unloading of a Progress cargo vehicle. This process is managed by the Russian ground control team with inputs from the U.S. team if U.S. hardware was launched on that Progress flight.

2.3.5 Inventory Management on ISS

The Inventory Management System (IMS) is the database that contains the official ISS inventory. The IMS database resides on ISS and at multiple locations on the ground. On ISS, the IMS resides on the file server but can be accessed from any laptop. The crew may also use the hand-held Bar Code Readers (BCR) to record changes to inventory (Figure 7). The Inventory Stowage Officer (ISO) and the Russian Inventory Stowage Specialist (RISS) may also enter changes to the onboard inventory to help alleviate some of the crew time required to properly maintain the database. Each crew member is allocated on the order of 20 minutes per day for IMS updating. Changes to the database are exchanged electronically between the ISS, Mission Control Center-Houston (MCC-H), and Mission Control Center-Moscow (MCC-M) IMS modules on a daily basis.

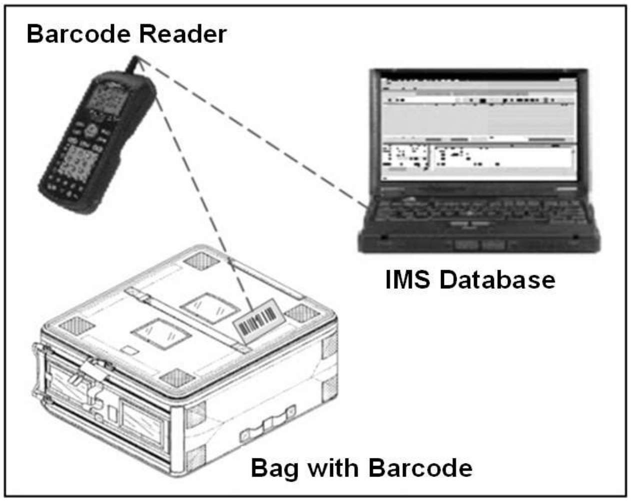


Figure 7: ISS Inventory Management System

Prior to each flight to ISS, whether it is a Shuttle, Progress, or Soyuz, a dataset containing all the necessary information on the resupply items is provided to the ISO team. The dataset is an Excel file that can be automatically loaded into the IMS. For Progress flights, the ISO team builds plans in IMS that updates IMS as the crew unloads the vehicle and stows the items. The crew can also use the BCR or call down their accomplishments at the end of each day. Due to the high activity level during Shuttle flights, the crews usually ask the ISO on console to update IMS with the transfers completed that day.

2.3.6 Stowage Planning for ISS

The Inventory Stowage Officer team performs stowage planning for U.S. items on ISS. The ISS stowage planner determines the final stowage locations for all U.S. items transferred to ISS from any launch vehicle. ISS stowage locations are provided to the transfer team for inclusion in the transfer list. For those items that cannot be transferred to their final stowage locations during the Shuttle flight, an unpack list is generated by the ISO team. After Shuttle undocks, the unpack list, an Excel spreadsheet, is up-linked to the crew. As the crew unpacks, they can choose to update IMS themselves, use the BCR, or call down the completions to MCC-H. If the crew chooses to call down their completions, the ISO on console will update IMS.

2.3.7 Trash

2.3.7.1 Trash Staging

Each day the crew generates common trash. Common trash is defined as food waste, used wipes, dirty clothes, and used hygiene items. This trash is collected into trash bags. Solid and liquid human waste is collected into special containers. All trash is staged in the aft portion of the Service Module for future packing into the departing Progress vehicle. Broken equipment is usually left in its current stowage location until Progress trash packing is initiated. The U.S. team schedules time prior to the actual Progress packing for the U.S. crewmember to gather the U.S. items for disposal and pack into the Russian provided trash bags. A photo of the completed trash gathering is taken so that the Russian team can determine the amount of volume that the U.S. items will require.

2.3.7.2 Trash List

Before any U.S. item that is not designated as common trash can be considered for disposal on Progress, a Waste Manifest Request (WMR) must be submitted. Approved WMRs are then collected into a change request and approved by the community. For the U.S. trash gathering activity, the trash ISO uses the approved waste CR to generate a crew message identifying which items should be collected for disposal. This message is an Excel spreadsheet and is up-linked via the Orbital Communication Adapter (OCA) to the ISS crew. To accompany the electronic crew message, an IMS plan is built so that the crew can update IMS, if they choose, as they execute the crew message. The crew may also use the BCR to track their trash gathering as they retrieve the U.S. items and pack them in the Russian-provided trash bags. Although the IMS plans and BCR are available, the primary method that the crews have used to report trash gathering has been a voice call-down to MCC-H. An ISO then updates IMS with the changes. It is ultimately the diligence of the crew that ensures that valuable items are not accidentally disposed of with the trash.

2.3.7.3 Trash Packing into Progress

Approximately one week prior to the planned undock of the Progress vehicle, the crew begins packing the trash items into the vehicle. The Russian team provides the crew an OCA message that directs them where to place each approved trash item. IMS is usually updated by the RISS after trash packing is complete.

2.3.8 Return

Items must be manifested for return using the same process that applies to launch items. Stowage plans are developed for the return vehicles. The ISO team uses the approved CRs and stowage drawings to develop a pre-pack list. The pre-pack list is an Excel spreadsheet that provides the crew with direction on which items to collect and how to pack them for return. CTBs, which are the primary method of collecting items for return, are labeled and staged for easy retrieval during transfer operations. To accompany the Excel spreadsheet, an IMS plan may be built to help the crew with updating IMS as the pre-packing occurs. The crew may opt to report accomplishments at the end of each day and have the ISO on console update IMS.

2.4 Assessment of Current Logistics Practices

The current Shuttle/ISS logistics system has many advantages and disadvantages. The current system is seen as a large improvement over the logistics systems used in past space programs such as MIR and Skylab. The system works well and training for crew and ground personnel is minimal.

The shortcomings of the current system include a high-level of complexity, redundancy of information/lack of a common database, and a large human-in-the-loop component. The complexity of the system is so great that it is difficult to find a person in the Space Shuttle Program or ISS Program that understands the entire process. Figure 8 illustrates the interaction of just some of the numerous documents and databases that govern the Shuttle/ISS logistics flow.

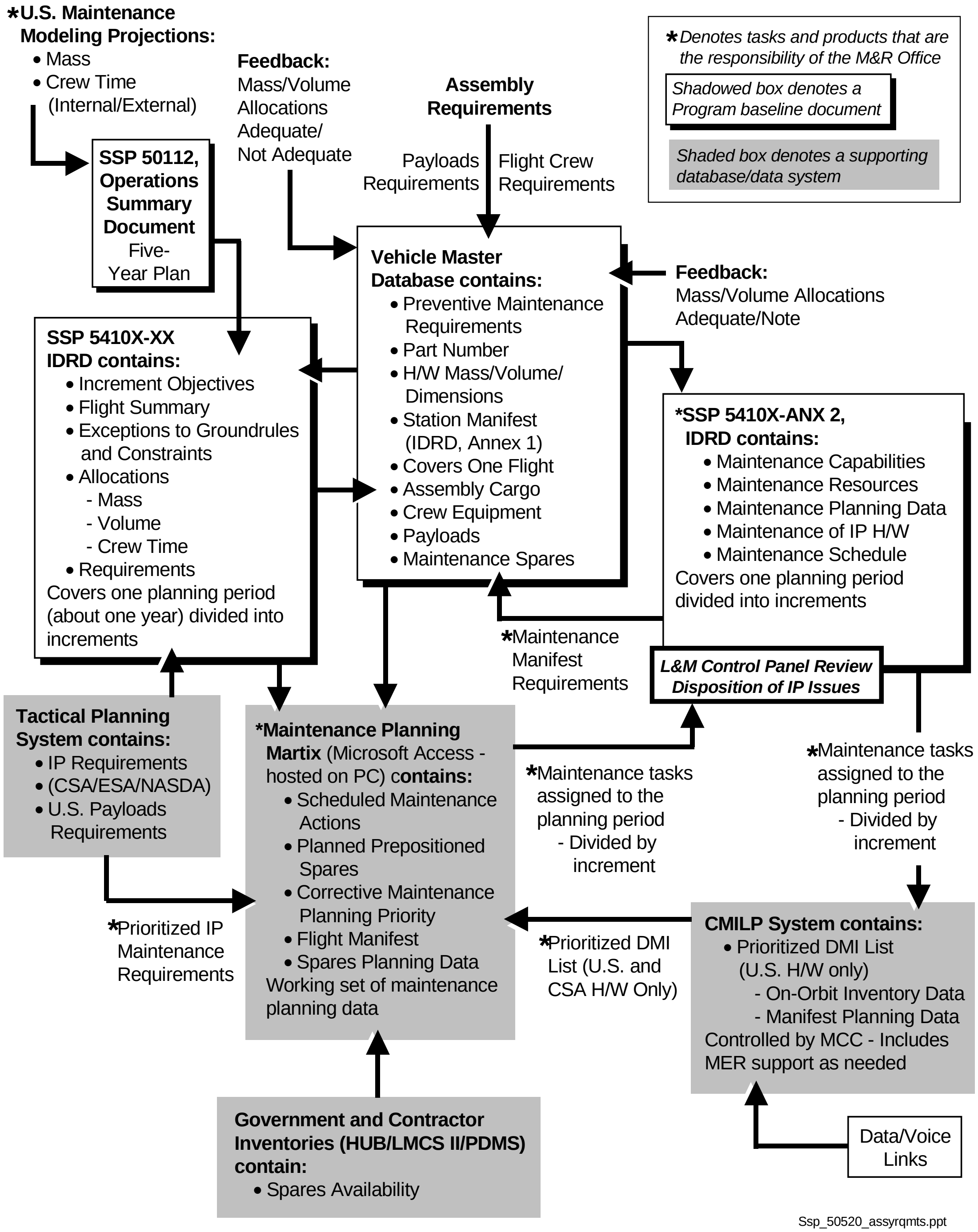


Figure 8: ISS support planning process

The lack of a common database to handle manifesting, inventory management on the ground, and on-orbit inventory management is another weakness of the current system. Presently there are separate databases/applications to do manifesting, ground tracking, manage the parts catalog, on-orbit inventory management, etc. Very few, if any, of these databases can interact with each other, causing a lot of extra work for personnel who need to transfer information between the systems. This extra human intervention also expands the chance that an error is made.

As was stated above in section 2.3.5, the current method of inventory management on the ISS is based on the Inventory Management System (IMS) and barcode readers. While this system is reliable (only 2-3% of items on ISS are tagged as "lost"), it is also very time consuming. Significantly more than the allotted 20 minutes per day are spent by the crew for managing the onboard logistics.

The ISS has also experienced a shortfall of stowage space. Some of this is the result of the reduced Shuttle flight rate and down mass capacity and some of it stems from an inadequate consideration of stowage and micro-logistics inside the ISS during station design and planning. Resultantly, spaces that were never intended for stowage, such as the joint airlock, the pressurized mating adapters (PMAs), and the Russian docking compartment, are being used as closets (Figure 9). This "overflow" of stowage affects the habitability of the ISS and adds additional time to on-board activities that require accessing any of locations being used as closets. It also affects crew morale.

Figure 9: The Overflow of ISS Stowage in the Joint Airlock
[http://spaceflight.nasa.gov/gallery/index.html]

Another example of the complexity involved in space logistics can be easy illustrated in the breadth of nomenclatures used to describe a "container type-device". Table 1 below shows a sampling of the nomenclature used by the Space Shuttle and ISS Programs to identify "containers". On one hand, this large number of terms does reflect the real complexity involved in space logistics, on the other hand the excess may be due to a lack of coordination across programs and could be interpreted as superfluous complexity.

Table 1: Nomenclature Survey

- Pocket
- Container
- Carrier
- Module
- Segment
- Compartment
- Element
- Pallet
- Assembly
- In-space Facility
- Node
- Vehicle
- Item
- Drawer
- Kit
- Locker
- Unit
- Rack
- Lab
- Platform
- MPLM
- Payload Bay
- Fairing
- Component
- Subsystem
- System
- SRU
- LRU
- ORU
- CTB
- M-01
- M-02
- M-03

It should also be noted that accommodation mass can consume much of the useful payload mass of a launch vehicle. The comparison in Table 2 below shows that for Shuttle the fraction (percentage) of useful payload mass is significantly lower than for a dedicated logistics vehicle such as Progress. The mass of the orbiter is a "payload" in terms of the Shuttle first stage (SRBs) and ET, however much of the useful payload mass for Shuttle is consumed by the accommodation mass described in Sections 2.3.2 and 2.3.3. This effect is slightly more pronounced when the Shuttle launches to an inclination of 51.6 because the dry mass of the orbiter acts as a lever, further reducing the relative percentage of useful upmass capability. Efforts will have to be made to explicitly account for and design accommodation mass into the system both for crewed flights of the CEV as well as robotic resupply or pre-positioning flights.

Table 2: Mass Comparison (Note: Shuttle numbers are given for the MPLM configuration.) [12][13][14]

Mass (kg)	**Shuttle (i=28.5)**	**Shuttle (i=51.6)**	**Soyuz-TM (i=51.6)**	**Progress-M (i=51.6)**
Total launch mass (TLM)	2,032,000	2,032,000	290,000	290,000
Vehicle dry mass	76,985	76,985	6,190	4,740
Total propellant mass	11,853	11,853	~880	1,750
Basic performance	17,690 (@ 407 km)	17,055 (@ 407 km)		
Accommodation mass	2,288 (general overhead) 4,491 (MPLM tare mass) 1,204 (flt-spec overhead) 3,044 (ISPRs, etc.)	2,288 (general overhead) 4,491 (MPLM tare mass) 1,204 (flt-spec overhead) 3,044 (ISPRs, etc.)	81 (seatliners)	(included)
Useful payload upmass	6,481*	6,028**	479	2,550
Useful payload downmass	6,481	6,028	439	1,700 (all destructive)
% payload upmass as a fraction of total launch mass (TLM)	0.32%	0.30%	0.17%	0.88%

* Limited by MPLM maximum payload of 9,071 kg less 3,044 kg accommodation plus mid-deck capacity of 454 kg
** Limited by Shuttle basic performance

3 Lessons Learned from Past and Current Human Spaceflight Programs

The bulk of the work performed in this study was focused on gathering lessons learned from NASA's past and current human spaceflight programs. The following sections describe the methodologies and results of this effort.

3.1 Ground Rules and Assumptions for Data Analysis

We began our research by making some ground rules and assumptions:

A. Multiple space programs have maintained some form of lessons learned data
B. Logistics lessons are not always straightforward
C. There are usually different views of logistics lessons
D. Limited lessons learned data is available
E. Lessons, either learned or repeated (and not learned), are valuable information

Each of the ground rules or assumptions involved some preparatory work in order to adequately take them into account.

A. Multiple space programs have maintained some form of lessons learned data.
To consider the perspectives on logistics lessons, we searched several sources within NASA, including organizations with direct and indirect connections with the system flow in mission planning. We utilized crew debriefs, removing all reference to individual crew members and missions. We made use of John Commonsense, the lessons repository for the Mission Operations Directorate since Apollo. We used the Goddard Space Flight Center Flights Programs and Projects Directorate (FPPD) database and searched the Skylab Lessons Learned databases at both Johnson Space Center and Marshall Space Flight Center. Finally, we used the public version of the Lessons Learned Information System (LLIS) and verified that we received the same result using the internal version of LLIS for our logistics lesson searches. See Appendix E for a complete listing of the resources used in our search.

B. Logistics lessons are not always straightforward.
To address the issue that there are many terms used to describe logistics, we developed a taxonomy, using both a selection from the body of knowledge from SOLE - The International Society of Logistics and from our experience as space flight operators. The proof of this ground rule is fairly easy to demonstrate. We ran a search on LLIS and found two hits using the word logistics, 16 with the word stowage, 28 with the word maintenance, etc. Logistics functions, as defined in Blanchard [7], provided the framework for our search.

- Logistics
- Packaging
- Handling
- Transport
- Maintenance
- Parts
- Supplies
- Spares
- Support
- Manifest
- Inventory
- Accountability
- Tracking
- Stowage
- Design
- Trash
- Shipping
- Warehouse
- IMS
- Pre-pack

Figure 10: Logistics Lessons Taxonomy

C. There are usually different views of logistics lessons.

We stated, as an assumption, that there were multiple perspectives—most notably those of the project/program manager, design engineer, logistics analyst/engineer, ground controller, crew member, and business manager. We decided to design role perspectives into a survey at the end of the research and note perspectives as we found lessons. This was not always possible with all resources shown in Appendix E.

D. Limited lessons learned data is available.

Our assumption was that there was little data available for a single on-orbit node or mission. We believed that we needed to find sources of lessons that covered at least the Phase I /Mir and the Skylab, in addition to the data available for the ISS, in order to get any significant amount of data.

E. Lessons, either learned or repeated, are valuable information.

We believed that we would find more affirmation of developments and capabilities than negative references, but we made this ground rule so that we could capture both. Lessons are not problems; they are something learned by performing a task either correctly or incorrectly. In most cases, what we found was that logistics lessons are noted as unmitigated and then repeat themselves, program after program.

3.2 Methodology for Data Analysis

Once the ground rules were established, our next task was to conduct the research of lessons learned, utilizing multiple databases (see Appendix E), and consolidating the data into a single spreadsheet. In some cases, we searched relational databases (e.g. LLIS) for the set of keywords listed in Figure 10 that we developed for this purpose. In other cases, we combined a review of the documents (e.g. JohnCommonsense, Apollo Mission Histories) and our knowledge of logistics to pull out the related lessons. We reviewed the crew comments, sanitizing them to take out restricted information such as the identity of individuals, the missions, etc. We also did some limited interviews with Shuttle and ISS flight controllers.

Our search returned approximately 300 lessons learned regarding space flight logistics. The 300 filtered and edited lessons learned are included in this report as Appendix A. Keywords were then applied to the gathered lessons for the purpose of sorting and evaluation. Once the lessons were compiled, an analysis of the resulting data was performed, first sorting it by keyword, then finding duplication and root cause, and finally sorting by root cause. The root cause analysis used a simple fishbone diagram [8] for cause and effect mapping to derive the root lessons.

Once this analysis was done, in order to gain perspective, the interim product was distilled to derive the root lessons from the data. The result revealed agreement between the independent views of the lessons, with seven top lessons prevailing. The top seven lessons learned are detailed in Section 3.3.

Finally, a survey was designed to validate the lessons learned research in current programs. The survey used the lessons themselves as a framework to measure exposure to the lessons, knowledge of the problem, expectations for future programs, and role-based perspectives on the lessons surveyed. The formation and results of that survey are discussed in Section 4.

3.3 The Top 7 Lessons Learned

The following seven lessons represent the review of nine separate data sources (Appendix E) for lessons learned across programs, centers, and activities. This list is an attempt to look across perspectives to derive a root lesson and address the root causes.

1. **Stowage** is the most mentioned lesson in all databases. Resulting problems from lack of stowage specification may include growing time demands for the crew, loss of accountability, loss of access to operational space, limits to housekeeping, weakened morale, and an increased requirement for re-supply. Potential mitigation is to include stowage requirements (volume, mass, etc.) in the design specification.
    1. Reconfigurable stowage volume is recommended.
    2. For high turnover, small items, pantry stowage is recommended (i.e. resupply the pantry, not the items in it).
    3. A system for naming and numbering stowage volumes should be established and maintained.
    4. Entryways, docking compartments, and other interconnections must take into account pass-through and cargo transfer operations.

2. A **common logistics/inventory system,** shared by multiple organizations would decrease the problem of differing values for like items across systems. Configuration management is enhanced with this type of system architecture, as well. Additionally, a single inventory system lends itself to a common naming system.

3. **Packing lists and manifests do not make good manual accounting systems**. Parent-child relationships are fluid and need to be intuitively handled by a system updated by the movement of both parents and children.

4. **Commonality** should be a prime consideration for all vehicles, systems, components, and software in order to minimize training requirements, optimize maintainability, reduce development and sparing costs, and increase operational flexibility. Failure to do this increases the logistics footprint.

5. **Design for maintenance** should be a primary consideration in reducing the logistics footprint. Smaller parts may be possible for repairs, consistent with the ability to test the sufficiency of the repair and the tools and training provided to the crew. An optimization is preferable, taking into account tools, time, packaging, stowage, and lifecycle cost.

6. **Plan for and apply standards** to system development. Multiple standards applied to the same area increase the logistics footprint. A simple example of this is standard and metric tools. In most cases, where there are multiple standards, there is an interface required, and the interface then requires support. A corollary to this is the use of commercial off the shelf (COTS) hardware. Unless it is delivered built to an existing standard, it automatically becomes a source of extra support requirements.

7. Include **return logistics** in the design specification. Need to understanding and model packaging requirements, pressurization, and reparability/disposability for the return or destructive reentry of items ahead of time. Trash growth and disposal should be modeled as part of the crew timeline.

4 Space Logistics Community Survey

We developed a Space Logistics Community Survey by integrating the top 7 lessons learned into a 10-part questionnaire (Appendix B). Most questions asked the respondent to rate his/her level of observance of each issue (e.g. the use of commonality in vehicles, system, or software) in current crewed spaceflight practice as well as his/her level of recommendation for each. The group of approximately 80 who were notified of the survey were selected as either participants of a Space Logistics Workshop [9] or as others affiliated with the areas of Space and Logistics. The participants were notified by email and told that their personal information would be kept confidential to ensure the fidelity of the data. The analysis is based on the 35 responses that were received. See Appendix C for a listing of survey respondents.

4.1 Survey Methodology

Data was collected using a web-based form. Each participant filled out the survey online and the responses were emailed directly to the survey administrator. The administrator collected the data as a series of numbers, 1-6, each referring to a measure on the scale used for that question (e.g. scale: 1. Unnecessary, 2. Somewhat Unnecessary, 3. Neutral, 4. Recommended, 5. Strongly Recommended, 6. N/A). After all the data had been received and collected, it was analyzed for observable patterns and statistical significance.

A copy of the survey used in this study is accessible at http://spacelogistics.mit.edu/survey/startpage.htm.

We distributed requests to complete the survey by email to all the participants with the web link. A copy of the survey is included in this report as Appendix B.

4.2 Results and Statistical Significance

4.2.1 Statistical Tests

Both chi-squared and t-tests were performed on the data to test its statistical significance. The chi-squared test is a test for independence of the data. For each question, the test was performed to determine whether the data was independent from a random result. The responses were compared with the baseline value of a random response for all questions. A random response was represented as an even ranking of all possible answers by the participants. Table 3 below shows the response to the question of the relative importance of logistics practices and the percentage likelihood that the results could be due to chance.

Table 3: Relative Importance of Logistics Practices

Surveyed Element	Rank	X^2	Confidence
Design for maintenance considerations	1	0.5%	99.5%
Use of commonality in systems	2	27.9%	72.1%
Design of an integrated inventory system	3	8.4%	91.6%
Design for stowage considerations	4	21.0%	79.0%
Planned use of standards in system development	5	47.0%	53.0%
Design for return logistics	6	0.2%	99.8%

What this table shows is that *design for maintenance* was considered the most important consideration and *return logistics* the least among the six practices with strong confidence in the data, 99.5% and 99.8% likelihood respectively. Similar calculations were performed for all questions in the survey, showing a propensity for a chi-square value under 10% for those questions that asked about recommended future considerations and about 20% for those questions regarding previously and currently observed space logistics practices. In other words, for the questions in which the respondent was asked to rank how they recommended an issue for the future, the result was significant with 90% confidence. For questions asking about observance in current practice, responses were significant with an approximate confidence value of 80%. With a sample size of 35, these responses show a high measure of fidelity according to the chi-squared test.

A t-Statistic test was used to compare how responses varied among the role of the participant in his/her organization. T-statistics are used to compare two sample sets of data to determine whether the underlying populations have the same mean. In this context, it was used to determine whether two sets of data were statistically different from each other. The ranking of importance for the six main logistics considerations is shown in Table 4 below. A “1” indicates the most important aspect identified and “6” the least important. For the most part, program/project managers had a slight variation in responses from the engineers, logisticians, and from the group as a whole.

Table 4: Ranking of Importance

	All	**Engineers**	**Logisticians**	**Program/Project Managers**
1	Maintenance	Maintenance	Maintenance	Maintenance/ Inventory/ Commonality
2	Commonality	Commonality	Commonality	
3	Inventory	Inventory	Inventory	
4	Stowage	Stowage	Stowage/ Planned Standards	Stowage
5	Planned Standards	Planned Standards		Return Logistics
6	Return Logistics	Return Logistics	Return Logistics	Planned Standards

We calculated a two-tailed non-paired t-statistic because for each pair of data sets there were two samples with unequal variances. This test was performed for each of the six possible pairs of data for engineers, logisticians, program/project managers, and the group as a whole (e.g. All v. Engineers, All v. Logisticians, Engineers v. Logisticians, etc.). The results illustrate the probability that the two sets of data being compared are statistically different from each other. The most significant differences were in how the program managers ranked compared to the rest of the group. There was an 87.9% significant difference between Program/Project Managers (PMs) and Logisticians in their ranking of return *logistics*. Similarly, comparing PMs to Engineers on their ranking of design for maintenance, there was an 88.1% difference. Somewhat surprisingly, there was a 92.4% difference in the way Engineers rank maintenance from the rest of the group. While each group ranks it as the top priority, Engineers do so overwhelmingly, leading to the large difference in the t-statistic. The rest of the data that was analyzed showed lower t-statistics in the data comparisons, making the differences in responses less significant. The full results of the statistical tests are shown in Table 5 below.

Table 5: T-test results showing the statistical difference between data

Statistical difference in ranking of	**All v. Engineers**	**All v. Logisticians**	**All v. PMs**	**Eng. v. Log.**	**Eng. v. PMs**	**Log. v. PMs**
Design for stowage considerations	0.508	0.480	0.384	0.726	0.073	0.552
Design of an integrated inventory system	0.229	0.350	0.057	0.087	0.101	0.171
Use of commonality in systems	0.579	0.156	0.334	0.385	0.599	0.390
Design for maintenance considerations	0.924	0.240	0.606	0.871	0.881	0.456
Planned use of standards in system development	0.407	0.202	0.318	0.478	0.559	0.082
Design for return logistics	0.757	0.971	0.513	0.900	0.103	0.879

While this data is certainly telling, it is somewhat less dependable than the statistics performed on the data set as a whole, since the groups become smaller when dividing them by role. Specifically, for the 28 participants that answered the previously discussed question, 7 identified themselves as engineers, 11 as logisticians, and 6 as PMs. It is important to note the difference in the way that the groups rank each factor, but the actual numeric comparisons should not be considered precise using the small data sets.

4.2.2 Data Charts

The rest of the results from the questionnaire are presented below. To compile the raw data into charts, a system of weights was imposed. All answers in the "Least Important" category were given a weight of one, with each succeeding category given an additional weight. For questions with six answer choices, the weights ranged from one to six with six being the "Most Important". For each question, the number of responses at each level in the answer scale were summed and then multiplied by their weight and summed all together to give a total score. Finally, all scores were normalized by diving the total score by the number of responses for that question, to give a normalized weight between zero and the maximum weight possible for that question. The charts compare the normalized scores of all possible answers for each question.

The overall relative importance of logistics considerations is depicted in Figure 11 below.

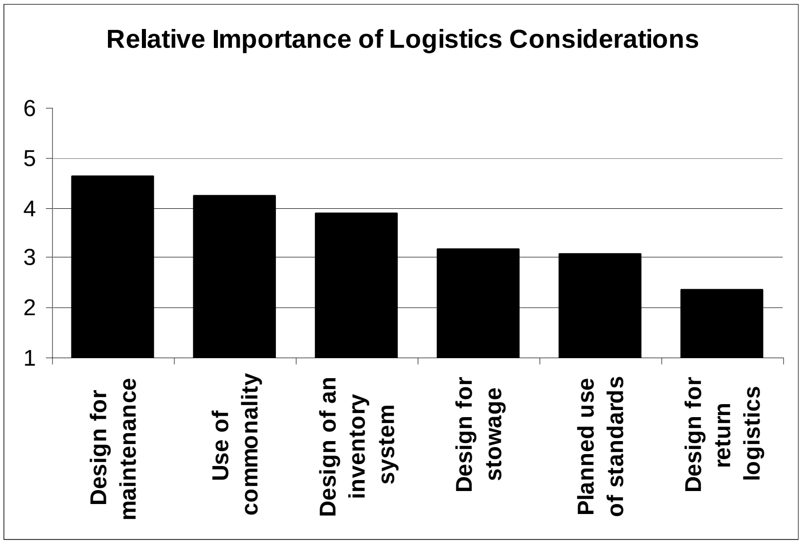


Figure 11: The relative importance of the top logistics lesson areas

However, when sorted by role, we see the slight divergence by program/project managers. While all roles agreed that maintenance planning was most important in the design, there were differing priorities beyond that. Interestingly, Engineers and Logisticians agree in all categories.

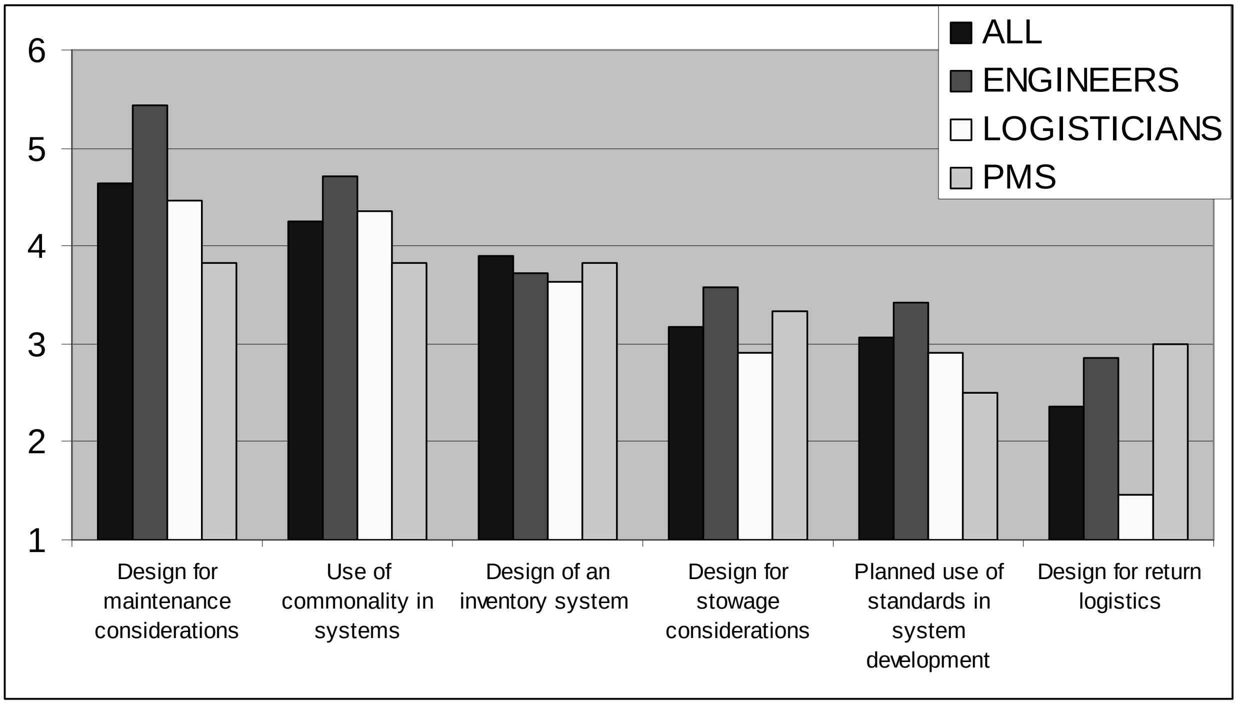


Figure 12: Relative importance of logistics considerations by role

Neither engineers nor logisticians correlated the importance of standards in the development of commonality, although that correlation was expected. Program/Project Managers rated all considerations differently from the group as a whole, giving maintenance, inventory, and stowage equal weight. They also did not correlate commonality and standards, showing a lack of connection between the two in the design and/or implementation process.

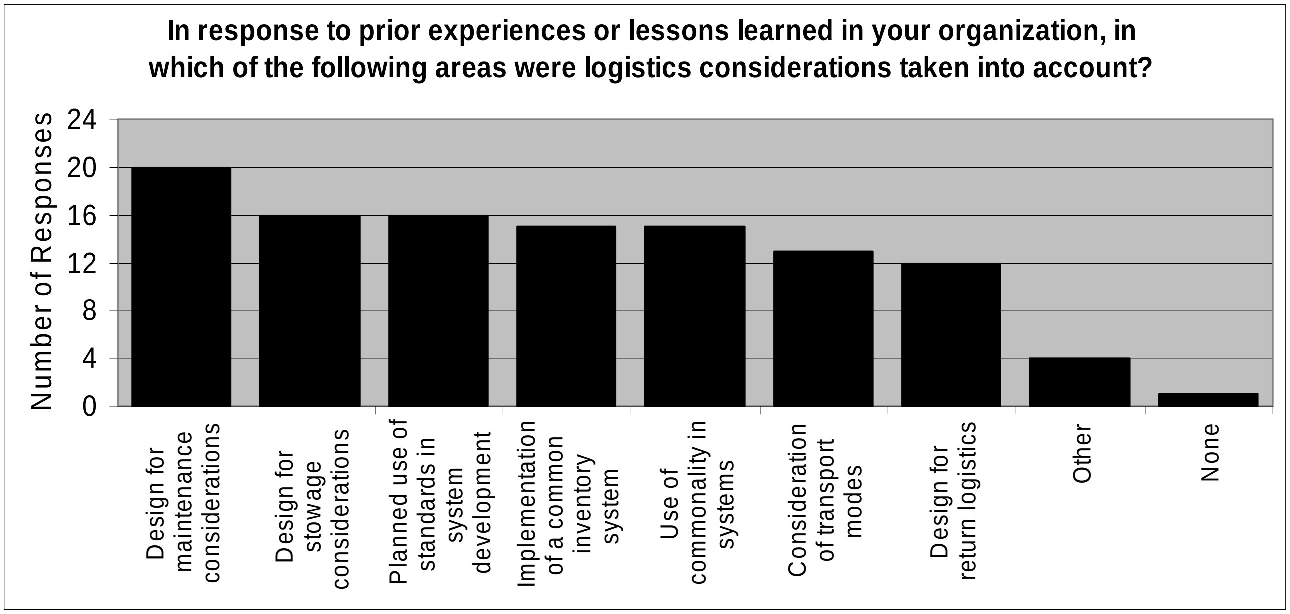


Figure 13: Ranking of previous efforts in addressing space logistics lessons learned

Figure 13 illustrates where emphasis on addressing these lessons has been placed in the past according to the respondents. In this question, it was asked where potential mitigation of problems had occurred in past experience. Maintenance again stands out as the overwhelming concern, with the others following relatively closely.

Figures 14-16 illustrate the gap between observed logistics practices in the past and recommended logistics practices in the future. Of the areas surveyed, including use of commonality, design for maintenance, design of an integrated inventory system, stowage considerations, and return logistics, three areas stand out as those requiring the most attention. Design for *commonality, inventory, and maintenance* all had noticeable gaps where observation levels did not meet recommendation levels. These are the areas that potentially need the most focused effort to close the gap. While Figure 13 shows that recent efforts have been directed towards improving design for maintenance in particular, *inventory* and *commonality* do not rank among the top previous efforts. These two issues in particular should be of high priority in future consideration of space logistics as they can also lead to large hidden costs.

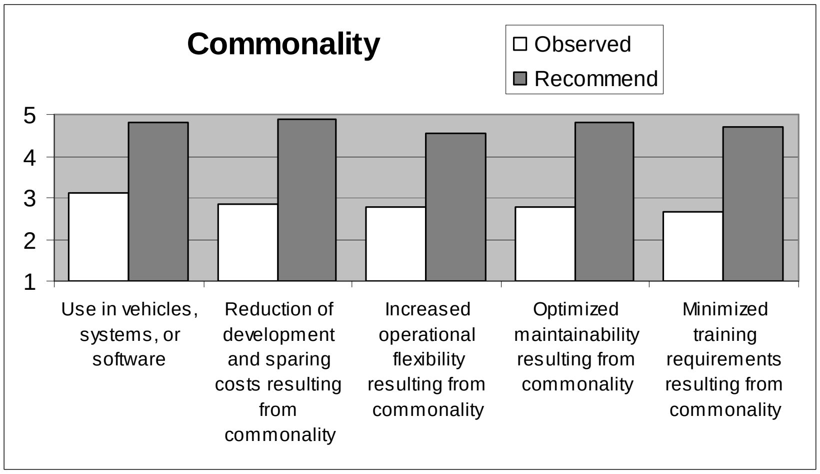


Figure 14: Observed and Recommended Commonality Measures

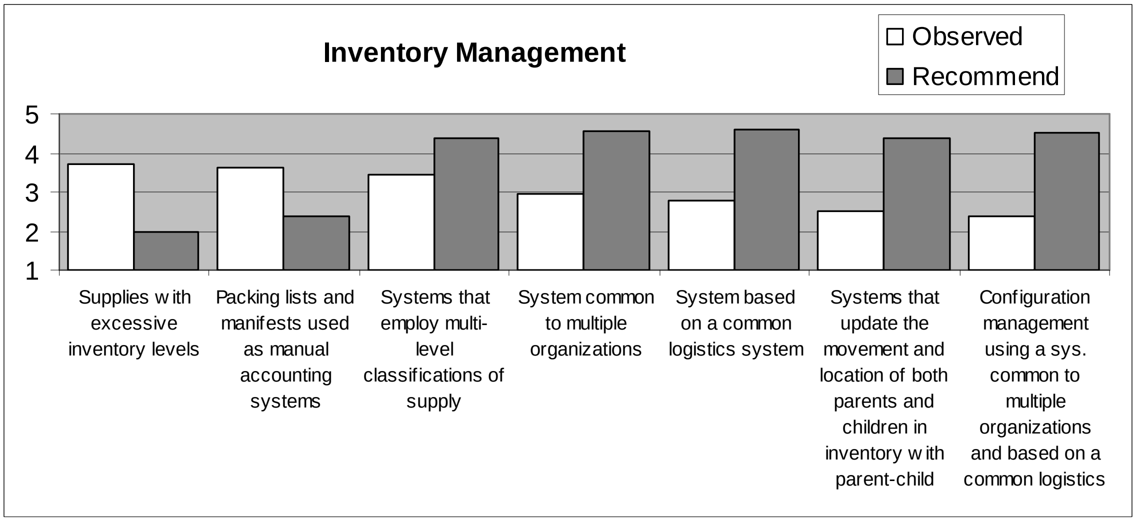


Figure 15: Observed and Recommended Inventory Management System Development

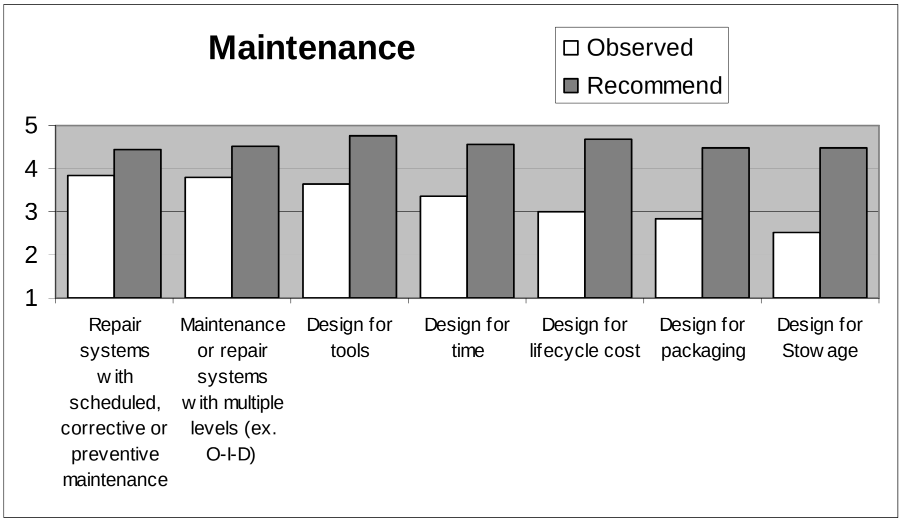


Figure 16: Observed and Recommended Emphasis on Maintenance Considerations

Additional charts compiled from the survey data concerning specific logistics lessons, including stowage difficulties and transport modes, are shown in Appendix D.

5 Conclusions

5.1 Analysis Method

It should be noted that our analysis method had some shortfalls. The first is that the LLIS is not a completely integrated Lessons Learned Information System. The other sources are a combination of documents and databases, but provide perspective that should be available in LLIS. A standard taxonomy might be helpful in general searches of the LLIS, which is instead divided into specialized areas. Logistics and disciplines such as systems engineering can only effectively apply lessons learned information if they are able to see multiple perspectives on the same problems. The method of analysis used here revealed that a standard regimen of reviewing lessons learned, consolidating them, and looking for root causes would probably allow broader use of the lessons in new developments and operational programs.

5.2 Current Space Flight Logistics

The current space logistics practices were reviewed for Shuttle and ISS and it was found that they represent a significant advance over the state of the art during Skylab and MIR. Nevertheless there is significant room for improvement. Interestingly, many of the current issues have their root in organizational issues, not purely technical issues. Areas of concern are:

- Fragmented databases between various logistics functions (manifesting, cargo integration, on-orbit operations) and organizations (NASA Centers, International partners). This dispersion of data leads to redundancies and errors and results in a large workforce to compensate for these shortcomings.

- Stowage issues on ISS are significant and are in part due to the lower flight rates experienced after the Columbia accident, and in part due to insufficient planning for micro-logistics during ISS development. Micro-logistics refers to the detailed flow of crew and supply items between modules and vehicles.

- Real-time awareness of system health and logistics inventory levels is challenging to obtain. While the bar-code based Inventory Management System (IMS) has proven to be effective, it is also time-consuming for the crew and ground controllers. New technologies such as Radio-Frequency Identification (RFID) could potentially alleviate this by transitioning to a more automated system, but technology maturation and system integration challenges remain.

- From an administrative and managerial perspective, the current ISS and Shuttle logistics processes are overly complex and bureaucratic and very few people are able to coherently describe the process in an end-to-end fashion. Whilst it is essential that on-orbit inventory be carefully planned, approved, and monitored, the processes to accomplish this could be significantly streamlined in future operations.

- Current logistics practices within NASA are structured along program/project lines, which can lead to inefficiencies when considering the costs and impacts of duplication of effort and inconsistencies in requirements as viewed from an Agency-wide perspective.

Also, it should be noted that the space logistics lessons learned presented in this report focus in particular on the space segment and that large capital investments and operational costs are tied up in the ground infrastructure and supplier network. Important lessons learned from the Shuttle and ISS programs exist in terms of dealing with technology obsolescence, strategic supplier relationships and long-term supplier viability as well as the establishment of policy directives and regulations that promote – rather than hinder – commonality, reuse and efficiencies across programs. We recommend a separate effort on capturing lessons learned from a ground infrastructure, logistics and supply chain management perspective.

5.3 Survey Observations

The perspectives of project managers, as opposed to engineers and logisticians, are appreciably different. In a system where decision-making is predominately top-down, this can lead to situations where priorities are not balanced with all perspectives. The survey pointed out specific areas where program managers view competing priorities differently from engineers and logisticians. This is perhaps a good direction for future research.

There is also a noticeable lack of correlation between commonality and standards for all groups surveyed. This seems to indicate that there is a misunderstanding of how to develop commonality. From the DoD (DoD Logistics Transformation Study [10]) to commercial logistics, there is a recognized requirement for both to exist for either to succeed. Again, this perceived difference between commonality and standards points to an area where further education and/or development can be established to enable proper use of either to be effectively implemented.

While stowage and inventory are ranked closely, there is a priority for inventory design over design for stowage. Visibility and easy accessibility of assets is the primary goal of both stowage and inventory management systems. Design for stowage benefits from the capability of tracking and locating stowed items. A common inventory management system allows for single source input of data, with a middleware connection to specialized data. We expected to see more of a correlation between these related functions in the future. Design for stowage and inventory management should be more closely linked to ensure effective use of both.

In the Figures 14-16 above, where there is a large gap between observed and recommended practices, there is evidence of either, mitigation, system design, or technology requirements in current and future systems. Virtually every area surveyed had highly recommended efforts where there was a low level of observation in current practice. Based on the *recommended* responses, the survey validated that the top 7 lessons learned are of considerable importance to all participants surveyed, whether from NASA, or the aerospace industry. While all had strong recommendations of logistics considerations, the ranking of observed practices was significantly lower. There was a notable need in areas where the observation did not meet recommendation levels, specifically in design for *commonality, inventory systems*, and *maintenance*.

While some of these may be areas of current mitigation, such as design for maintenance, as exemplified in a separate survey question, some may be areas where there is less ongoing development, as with the use of commonality and integrated inventory management. This study has proven beneficial in both pinpointing the areas of importance in logistics, but also in identifying the areas where further progress can be made.

5.4 Impact of Logistics on Flight Safety and Public Awareness

During the period that this report was assembled we have also monitored press releases and media reports regarding space logistics. Since the Columbia accident there has been significant interest in the relationship between traffic models and resupply capability, and on-board inventory. Additionally, there has been recognition both within and outside NASA that critical shortages and logistics related events – not just vehicle malfunctions – can have a profound impact on spaceflight safety and mission assurance.

Two events from the recent past - as reported by the media - illustrate this point:

Dec. 10, 2004, 12:24PM
Space station crew endures food shortage
NASA says a Russian capsule will bring supplies on Christmas Day
By MARK CARREAU
2004 Houston Chronicle

A food shortage on the international space station means its two crew members must eat less until a Russian supply capsule arrives Christmas Day, NASA officials said Thursday. Supplies are so low that if the usually reliable Progress spacecraft missed its delivery, American Leroy Chiao and Russian Salizhan Sharipov would be ordered back to Earth by mid-January, halfway through their six-month mission.

Mar 23, 2006 10:59: AM
ISS spacewalks on hold
ORLANDO SENTINEL

…
On a related note, mission managers said Wednesday that four canisters used to purge Russian spacesuits of carbon dioxide are missing. Station residents Bill McArthur and Valery Tokarev so far have been unable to find them. The issues are nothing new. Both have been known to NASA officials for some time and were mentioned in an internal ISS status report posted last week on SpaceRef.com. More details are available in stories from Reuters and The Associated Press.

It may be true that some of the reporting on space logistics events by the media may not always be grounded in fact or may be somewhat over-exaggerated. Nevertheless, it is becoming clear that effective logistics is essential in ensuring crew effectiveness and mission safety. This includes, but is not limited to the pre-emption of critical shortages, the incorporation of lessons learned on stowage, sparing requirements and consumables usage, and effective communications between the crew and ground controllers.

As Project Constellation lays the groundwork for a human return to the Moon, new vehicles and procedures will have to be developed – taking into account the lessons of the past – while addressing the challenges of the future.

6 Recommendations

As the Shuttle program comes to a close with anticipated retirement by 2010, we have come to realize that without the ability to collaborate, integrate and standardize the current decision making process relevant to logistics and the supply chain as a whole, NASA will find it increasingly difficult to work as an informed collaborator with suppliers and contractors in bringing new systems and sustainment processes to fruition. The cost of operating and sustaining the resulting systems will continue to grow, exceeding designated budgets. We have also come to learn that the path to optimizing operability and sustainability is by consideration of the entire supply chain.

As such, we recommend the following course of action to ensure that logistics is at the forefront of consideration for the Constellation Program and beyond, potentially leading to a substantial cost savings in operations:

1. Establish a list of **space logistics relevant requirements** that must be taken into account during development of the Constellation Program (CxPO) overall and CEV, CLV, CaLV, LSAM, EDS, and Lunar Outpost/Base design specifically, as well as adaptation of ground processing infrastructure.

2. **Empower a position responsible for logistics oversight** early in the process, the equivalent of a Chief Logistics Officer (CLO). This position should be in charge of creating and enforcing standards across program elements, identifying opportunities for lifecycle cost savings as well as ensuring that past lessons are taken into account when formulating future space flight logistics requirements.

3. **Space Logistics modeling and analysis investment**: Currently, among the technology areas recommended for funding by the ESAS report [11, Chapter 9], the areas on analysis and integration (11A, 11B) only have two logistics-related projects listed. Additional analysis, modeling and optimization investments for space logistics should be developed, validated and also applied to future considerations of operations and supportability including commonality, interoperability, maintainability, logistics, and in-situ fabrication (area 12A).

4. **Reduce the overlap in the logistics tracking system**. The lack of a common database to handle manifesting, inventory management on the ground, and on-orbit inventory management is a weakness of the current system. It is unrealistic to think that future programs will handle all these critical functions with one database but it is important to have fewer databases that can easily pass information amongst themselves.

5. **Automated inventory tracking and system updating**. There is a need to develop new technologies and integrated system solutions that allow for automated tracking of agents, supply items, and assets in the space logistics area, including automatic updating of inventory during cargo integration and on-orbit operations.

6. **Redesign and simplify packaging and stowage**. Current packaging and rack equipment on the Shuttle and ISS are modular and effective in protecting experiments and supply items from vibrations, shocks and other environmental hazards. However, accommodation mass and volume is significant and – in some cases – exceeds the mass of the useful payload itself. Accommodation mass and modular, reconfigurable stowage must be explicit considerations in the design of the CEV, LSAM, and other future flight hardware elements.

7. **Move the NASA knowledge capture into one system** (LLIS) and develop an ontology for assigning keywords. Additionally, there should be an effort to identify root causes and group lessons, which could easily be integrated into the relational database.

8. Institute **standard contract requirements, performance and evaluation criteria, and reporting requirements**. Having programs fully aligned in their logistics and supportability posture will appreciably reduce costs and improve responsiveness. Some areas where commonality can prove beneficial are:

- Certified Sources
- Contract requirements and management
- Cross-Project resources and materials

List of Abbreviations

ATV	Automated Transfer Vehicle
BCR	Barcode Reader
CEV	Crew Exploration Vehicle
CaLV	Cargo Launch Vehicle
CLV	Crew Launch Vehicle
CR	Change Request
CTB	Cargo Transfer Bag
CTBE	Cargo Transfer Bag Equivalent
DOD	Department of Defense
EDS	Earth Departure Stage
ESA	European Space Agency
ETR	Express Transport Rack
HTV	HII Transfer Vehicle
IMS	Inventory Management System
ISO	Inventory and Stowage Officer
ISPR	International Standards Payload Rack
ISS	International Space Station
JAXA	Japanese Aerospace Exploration Agency
JSC	Johnson Space Center
KSC	Kennedy Space Center
LLIS	Lessons Learned Information System
LSAM	Lunar Surface Access Module
MCC-H	Mission Control Center-Houston
MCC-M	Mission Control Center-Moscow
MLE	Middeck Locker Equivalent
MPLM	Multi-Purpose Logistics Module
MR	Manifest Request
MSFC	Marshall Space Flight Center
MWG	Manifest Working Group
OCA	Orbital Communication Adapter
PMA	Pressurized Mating Adapter
RISS	Russian Inventory Stowage Specialist
RSP	Resupply Stowage Platform
RSR	Resupply Stowage Rack
SSP	Space Shuttle Program
WMR	Waste Manifest Request
ZSR	Zero-G Stowage Rack

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Appendix A: Composite of 300 Lessons Learned

Event	Logistics applicability	Source	Number	Keyword(s)
Any comments on the usability of the BCR software?	Barcode system was inadequately sized to run application. A more generic discussion is the necessity to log users in and out on orbit. There are only six persons. A more reasonable implementation might be an open application that asks for the operator’s name.	Crew Comments	44	Barcode
Have there been any issues with cable or hose labels coming off?	Barcode labels come off, in particular the wraparound vinyl flaps.	Crew Comments	74	Barcode
Please comment on any Bar Code Reader (BCR) performance issues with respect to the location/module the barcode reader was being used (problems with scanning, delay in response time, etc).	Transactions involving more than three items were better handled using the computer display instead of the BCR.	Crew Comments	81	Barcode
There was a kit of various sized bar code labels provided for you to use as you chose. Did you ever find them necessary or useful? If so, did you use one of the labels more frequently than the others?	Crew will use barcode label size that fits the item.	Crew Comments	53	Barcode
Any comments on the communication between the crew and the ground regarding IMS?	Reinforce testing and training of barcode reader before flight.	Crew Comments	38	Barcode, IMS
Did we give you enough time to prepack items before a Shuttle flight? We duplicated the prepack paper plan in IMS, why or why not was that useful/helpful? What could have made it more useful for you?	Pre-pack is the preparation and pre-positioning of on-orbit cargo prior to arrival of the transport vehicle. This requires movement of the item(s) from their stowage position, kitting and subsequent stowage in staging area.	Crew Comments	32	Barcode, Prepack, IMS, Transfer
Do you have any comments on the ISS inventory audits? How effective and useful were they? Any recommendations for improvement?	Transfer kitting needs to be accounted for in IMS system. Storage locations should have barcoded labeling	Crew Comments	75	Barcode, Storekeeping, Packing
How much did you use the barcodes? Which barcodes did you use – those on bags, those on items, both? What did you use the barcodes for?	Transfer and packing kits need barcode labels.	Crew Comments	52	Barcodes
Consumables low-level indications	Low-level indications for consumables should be such that there will be sufficient time for corrective action without having to depend upon an emergency system. The indications should be available to the ground.	John Commonsense	N/A	cargo, consumables

There were too many sources of information for basic engineering data. Data was being obtained from multiple Payload Element Developer (PED) personnel, post-Acceptance Test (AT) results and destow data, many of which were inconsistent and did not agree with approved CCB data. These discrepancies made it difficult to control manifest information and maintain reliability of the data.	There are many users and customers for logistics information, a central repository and single points of contact will keep the information flow in synch.	Phase 1/MIR	2-9.	certification
Contractor building rehab job superintendent not available during construction meetings	Meeting attendance and participation may be a contractual issue requiring statement of work direction	NASA PLL	749	Communication
Add a logistics move coordinator to team in modification and rehabilitation projects	Add a logistics move coordinator to team in modification and rehabilitation projects	NASA PLL	860	Communication
During the flight, problems were noted with the ops nomenclature in O2/N2 procedures matching up with equipment labels on the O2 panel in the Airlock (A/L1A2).	Reinforce necessity of procedures and equipment nomenclature match.	Crew Comments	13	Communications Maintainability
	All rotating components must be designed to preclude fragmentation damage should a failure occur. The design of all rotating components should consider contribution to ambient noise levels in the crew cabin.	John Commonsense	N/A	Component design
Non configuration managed drawing used to service high voltage equipment	Using documentation applicable to configuration	NASA PLL	443	Configuration management, maintenance procedure
Bearing failure broke centrifuge due to excessive loading	Conduct testing and operations readiness reviews	NASA PLL	494	Configuration management, operations logs and situational awareness
Description of efforts to eliminate leaking reaction control system (RCS) valves	Changes to processing and design of a deployed component will have a logistics impact	NASA PLL	1000	Continued Product Improvement
Use of robotic removal of Solid Rocket Booster Thermal Systems	Continuous improvement can yield productivity efficiencies in post recovery refurbishment	NASA PLL	832	Continuous Process Improvement, Design for maintainability
Fasteners used in ground support equipment for the MPLM come loose and are tracked into module	Operations analysis should include realistic assessment of components subject to high traffic.	NASA PLL	1205	Continuous product improvement

How do you assess the process of cargo stowage for cargo that is: delivered, returned, and disposed?	Each crew will consume consumables at a different rate	Crew Comments	76	Crew Provisioning
No single database to control all pertinent payload manifest information. Multiple databases were controlled by multiple organizations, which did not communicate efficiently with each other. Data on the same hardware was inconsistent, throwing the reliability of all databases into question.	There are many users and customers for logistics information, a central repository and single points of contact will keep the information flow in synch.	Phase 1/MIR	2-18.	data; manifest
Late parts development caused unqualified parts to be installed until qualified parts were available	Unique design of space hardware imposes unusual logistics requirements, late deliveries and extensive work at launch site	NASA PLL	479	Delivery
EEE parts selection criteria	Reinforces necessity for creation, application, and enforcement of standards.	NASA PLL	725	Design
Use of concurrent design	Reinforces necessity for creation, application, and enforcement of standards.	NASA PLL	681	Design for logistics
Factors associated with spacecraft maintenance concept	Effective development of a maintenance concept can enhance the effectiveness of maintenance support planning and aid both logistics planning and design of a maintainable system. The maintenance concept can also provide assessments of cost savings for maintenance activities and resources allowable at each maintenance level	NASA PLL	724	Design for maintainability
Extra Vehicular Activity (EVA) event design considerations	Establish standards for tool, material and task design factors when performing EVA operations	NASA PLL	834	Design for maintainability
Use of proposed venting scheme reduces number of components in system	Reduction in material and maintenance costs	NASA PLL	854	Design for Maintainability
Benefits of Implementing Maintainability on NASA Programs	Implementation of maintainability principles can reduce risk by increasing operational availability and reducing lifecycle costs.	NASA PLL	835	Design for maintainability, Product lifecycle
Mean Time To Repair (MTTR) predictions	NASA has established guidance for MTTR prediction analysis	NASA PLL	840	Design for Maintainability, Systems Engineering
Availability Prediction and Analysis	NASA has established guidance for availability Prediction and Analysis	NASA PLL	841	Design for Maintainability, Systems Engineering

Design considerations when using composites	Reinforces necessity for creation, application, and enforcement of standards.	NASA PLL	682	Design for maintenance
Use of high reliability parts in design enhance reliability	Sparing and qualification of parts designated and qualified as high reliability	NASA PLL	709	Design for maintenance
Crew-use hardware such as fasteners, electrical and plumbing connectors, switches, circuit breakers, and screws, etc., should be standardized as much as possible to facilitate crew operations, reduce crew errors, and reduce crew training requirements. Each common usage also reduces total sparing levels. This approach will simplify design, documentation, sparing, and actual in-orbit usage.	Standardize and minimize variety of devices	JSC Skylab Lessons	1-15	design for maintenance, commonality
Designing preventative maintenance strategies using reliability centered maintenance (RCM) analysis	Process improvement revisiting preventative maintenance strategies based on performance data	NASA PLL	891	Design for maintenance, reliability and process improvement
Spacelab interfaces not standardized	Operators not involved during design phase caused mismatch of equipment to Spacelab	NASA PLL	326	Design for operations
Space fastener selection and design criteria	Reinforces necessity for creation, application, and enforcement of standards.	NASA PLL	675	Design for operations and maintenance
Microelectronic circuit design considerations	Reinforces necessity for creation, application, and enforcement of standards.	NASA PLL	678	Design for operations and maintenance
Microcircuit design experience documented in checklists	Reinforces necessity for creation, application, and enforcement of standards.	NASA PLL	680	Design for operations and maintenance
Spacecraft deployed appendage test guidelines	Ground based testing requirements must be coordinated with logistics to ensure GSE is available	NASA PLL	716	Design for preflight processing
Spectral fatigue reliability	Reinforces necessity for creation, application, and enforcement of standards.	NASA PLL	696	Design for reliability
Fracture Mechanics Reliability	Reinforces necessity for creation, application, and enforcement of standards.	NASA PLL	700	Design for reliability
Use of Government-Industry Exchange Program (GIDEP) and Failure Experience Data Exchange (FEDI) programs	These and similar data interchange programs contain significant problems are identified on parts, components, processes, equipment, materials, specifications, or safety hazards.	NASA PLL	805	Design for Reliability

Analyzing system reliability using block diagram models	Using block diagramming methods for model construction and predictive analysis	NASA PLL	825	Design for reliability
Quantitative Reliability Requirements Used as Performance-Based Requirements for Space Systems	Quantitative Reliability Requirements Used as Performance-Based Requirements for Space Systems	NASA PLL	827	Design for reliability
Maintainability Program Management Considerations	Establishing maintenance and logistics concepts early in the conceptual phase of the program	NASA PLL	831	Design for Reliability
Preflight testing exhausted power supply spares	For various reasons development activities may continue post delivery at the launch facility, planning and design must take this into account.	NASA PLL	601	development, sparing and pre-launch operations
Are there any other cargo areas that additional pantry groupings would be beneficial?	Stuff piles up when ground is reluctant to disposition equipment no longer required. Early on the crew found the plenum voids in the FGB a good place to store stuff. The Russian module manufacturer objected strenuously	Crew Comments	103	Disposal, Excess
Do you have any suggestions for aiding in the identification and selection of cargo items that are currently on-orbit which can be returned/trashed due to lack of use or any other reason?	Crew wants to advise on suitability of material for disposal. Proposed current and future end use for every item in inventory should be known for ground to provide timely approval on disposal.	Crew Comments	100	Excess, Storekeeping, Stowage
Do you have any suggestions for aiding in the identification of cargo items that are currently on-orbit which can be returned due to lack of use or any other reason?	Program needs to assess what equipment is to remain on orbit taking up space. Crewmember referenced an on board spare that can only be changed when orbiter is present and broken equipment still on-orbit.	Crew Comments	89	Excess, Storekeeping, Stowage
From a Habitability/Operations perspective, how would you describe the overall on-orbit stowage situation?	Ground needs to keep on top of disposing of no longer required equipment	Crew Comments	98	Excess, Stowage

Trash should be separated into biologically active and inactive material. Daily disposal of active material is necessary, whereas less frequent disposal of inactive material is satisfactory. Stowage of collected trash "external" to the habitable volume of the spacecraft is highly desirable. Food containers make up the bulk of the trash and should be designed to consume minimum volume when expended. A compactor seems like a desirable feature. Backups and contingency plans are necessary.	Separate trash into biologically active and inactive material	JSC Skylab Lessons	1-6	excess; trash
Project cancelled after it became apparent that proposal was inadequately prepared, reviewed and implemented	Logistics analysis required to determine adequacy of proposed implementation	NASA PLL	1366	Feasibility evaluation and assessment
Pre-flight Problem/Reporting Procedures	Considerable development work/testing may occur at the launch facility, documented anomalies are a significant factor in qualification and flight certification.	NASA PLL	733	Flight qualification, Flight readiness review, operational readiness review
Did you typically eat three meals a day?	Crew Eats three meals a day	Crew Comments	68	Food, Crew Provisioning, Timeline
Did you feel that there was enough variety in your eight-day menu cycle or does the cycle need to be lengthened?	Large variability in crew food preference	Crew Comments	66	Food, Provisioning
Non-flight hardware is critical to support program milestones and needs to be documented and transported with the same level of support as flight hardware.	Generally speaking the focus is on flight hardware, but it is just as important for non flight equipment to be where it's needed when it's needed.	Phase 1/MIR	5/37	GSE; transport
A comprehensive database was not developed early enough to track all NASA/Mir hardware. When the database was implemented, much of the hardware had lost traceability and could not be adequately tracked in the database. Also, the database had two disadvantages: - Links were never established to Payload Integration Planning System (PIPS), which could have served as the master database for the program. - Microsoft Access required more in-depth computer programming knowledge than traditional spreadsheets in order to make modifications.	Failure to have integrated stowage and manifesting tools before the advent of operations leads to inefficiencies and lost time.	Phase 1/MIR	5/9	IMS
Any comments on the communication between the crew and the ground regarding IMS?	Crews quickly weary of daily calls to locate on orbit items.	Crew Comments	38	IMS

Any comments on the communication between the crew and the ground regarding IMS?	Crew believes there should be tighter integration between performance of procedure, e.g. installation of component, and follow-up IMS update	Crew Comments	38	IMS
Do you have any suggestions for enhancements/improvements to the IMS software?	System should be able to locate available empty stowage	Crew Comments	39	IMS
Do you have any suggestions for enhancements/improvements to the IMS software?	Suggested IMS improvements: Hourglass indicator to show processing is occurring Full screen as default Introductory logo displays take up time Server needs to be more responsive	Crew Comments	39	IMS
How do you assess the search for and inventory of items, and working with the IMS?	The crew primary search function used numbers instead of names for items.	Crew Comments	77	IMS
How much daily overhead is there to keep the IMS database updated to reflect the daily changes? Do we need to add this to your daily timeline?	At least one hour of work daily required maintaining IMS; this time was not timelined.	Crew Comments	29	IMS
IMS can display the data in a "tree" or graphically. Which do you prefer? Are they both beneficial? What changes and or improvements would you make?	IMS can display the data in a "tree" or graphically, Crewmember noted that tree was preferred.	Crew Comments	46	IMS
IMS performance (loading time, response time during searches, etc.) has been an issue in the past. Different crewmembers have given varying responses on the “lack of performance”. Could you please offer your opinions?	IMS server and LAN are not adequately sized to handle traffic	Crew Comments	83	IMS
The program office is now supplying dimensions (length, width, height, mass) in IMS for many of the new items flying up. Would dimensional data in IMS have been any use for your work?	Dimensional information in IMS assists in search for item	Crew Comments	88	IMS
Was the search capability easy, adequate, or cumbersome to use?	Synonym capability would be desirable in locating items along with English names for Russian items.	Crew Comments	43	IMS
Was the time that Russia scheduled for you to transfer/stow items and update IMS post Progress docking sufficient?	Adequate time to properly update the IMS must be accounted for in the crew timeline.	Crew Comments	31	IMS
What are some troubleshooting issues that should be addressed by training?	Add indicator that software is working or when application needs to be restarted	Crew Comments	48	IMS

What were the least used features of the software?	Graphical features of software were not used	Crew Comments	41	IMS
What were the most used features of the software?	Search and move capabilities of software were used most often	Crew Comments	40	IMS
Which IMS capabilities did the crew feel needed better emphasis from a training perspective?	Ensure crews receive adequate IMS training on ground	Crew Comments	47	IMS
In about 5% of your BCR scans, the BCR misinterpreted a barcode. Can you comment on the condition of the barcodes (i.e. dirty, scratched) that you scanned that gave erroneous information?	Barcode reader had difficulty reading curved surfaces.	Crew Comments	82	IMS, Barcode
Do you have any comments on the ISS inventory audits? How effective and useful were they? Any recommendations for improvement?	During inventory audit activities the crew prefers that ground perform data entry	Crew Comments	75	IMS, Storekeeping
A practical and streamlined equipment stowage inventory management and accounting system is needed during the mission operations phase of the program. The system should output crew data in the exact format to be used by the crew and should be compatible with the real time uplink to the orbiting spacecraft for presentation on board. The system should also track other onboard data references affected by a given stowage change.	It's easy to lose sight of the crew interface as the various logistical information management systems are devised	JSC Skylab Lessons	8-7	IMS, stowage, inventory, storekeeping
Do you have any comments on the ISS inventory audits? How effective and useful were they? Any recommendations for improvement?	Inventory audits are useful	Crew Comments	75	IMS, stowage, inventory, storekeeping, audit
General Crew Comment	Crew works directly with an Inventory and Stowage Officer (ISO) console position who is solely responsible for providing help.	Crew Comments	21	IMS, Transfer, Stowage
Observation: Tracking hardware manifests is a labor intensive job that requires dedicated personnel. Background: Numerous documents are developed by various organizations for different purposes and formatted differently although they all contain a large percentage of common information. Examples include the MMO Manifest, the WG-6 004 document, the Phase One Requirements Document and the Phase One 0005 document. At present a great deal of manpower is expended trying to ensure the various documents are in agreement. Recommendation: Develop a hardware tracking database which has common use for all organizations and which is accessible by all parties. Dedicated	Despite prevalence of computers, databases and associated reports, many organizations and programs are document driven. Any logistics apps must be integrated and allow for collaborative activities	Phase 1/MIR	2-2.	IMS; manifest; inventory

support (including knowledgeable engineers as well as software experts) is required to maintain this database and ensure its accuracy.				
Every item that is on ISS must be expected to be returned from ISS on Shuttle or any other manned return vehicle.	Single mission execution processes must be adapted when planning a multi-mission campaign. This LL is not applicable to a destination operations environment.	Phase 1/MIR	3/1	IMS; manifest; inventory
On-board inventory tracking and return prep readiness checking needs help.	Failure to have integrated stowage and manifesting tools before the advent of operations leads to inefficiencies and lost time.	Phase 1/MIR	5/1	IMS; prepack; stowage
A user-friendly, graphics-based configuration tool was never developed to allow the ground team to perform real-time assessments or emergency replanning of hardware/stowage relocations on Mir.	An integrated stowage and analysis tool is desirable.	Phase 1/MIR	3/16	IMS; Stowage
There was no convenient portable method for recording inventory. Long duration crewmembers were of the opinion that the ground did not need to know in detail where every piece of hardware was located and therefore, did not want to do inventories. They felt that as long as the crewmember onboard was aware of the location of hardware, that should be all that was required (even after the Spektr collision). They also felt that the onboard crewmember is the best source for identifying where hardware should be stowed and the one to provide the resupply bag stowage plan. Most crewmembers do not think the bar code reader is the solution.	There are pros and cons to the various inventory management strategies practiced in the space program. Factors such as ease-of-use and practicality must be considered when designing a system.	Phase 1/MIR	5/29	IMS; stowage
A Spektr inventory was performed during NASA 2 and files were left for the NASA 3 crewmember. In addition, the NASA 3 crewmember would send down updated files when he relocated hardware.	To keep accurate stowage locations of on board inventory, daily call downs may be necessary.	Phase 1/MIR	5/30	IMS; stowage, inventory
Personnel moves require facility setup and infrastructure installation	Institutional logistics is generally responsible for ensuring facilities meet user's needs	NASA PLL	746	Infrastructure
Lack of availability of standard office equipment hampered Columbia accident board investigation	Institutional logistics rapid response to infrastructure needs aids investigation	NASA PLL	1453	Institutional logistics
Lack of availability of office space hampered Columbia accident board investigation	Institutional logistics rapid response to infrastructure needs aids investigation	NASA PLL	1455	Institutional logistics

Lack of availability of IT hampered Columbia accident board investigation	Institutional logistics rapid response to infrastructure needs aids investigation	NASA PLL	1456	Institutional logistics
Lack of witness interview processes and equipment hampered Columbia accident board investigation	Institutional logistics rapid response to infrastructure needs aids investigation	NASA PLL	1458	Institutional logistics
Lack of accident scene documentation equipment hampered Columbia accident board investigation	Institutional logistics rapid response to infrastructure needs aids investigation	NASA PLL	1461	Institutional logistics
Application of development collaborative information management and modeling tool inconsistent through accident investigation	Institutional logistics rapid response to infrastructure needs aids investigation	NASA PLL	1475	Institutional logistics
Individual hardware suppliers should not independently establish hardware quantities required for program activities. The program organization must establish a consistent approach in determining quantities of equipment required to support a program. A combination events chart and requirements checklist was a useful tool for quantity determination.	The development and deployment of space equipment involves many versions (flight, training; test article, etc) of the equipment for a myriad of users.	JSC Skylab Lessons	1-21	inventory, classification
Resupply of the station is an international and complex endeavor covering clothes, food, tools, and the like. The international aspect of logistics coupling differing cultures, ops concepts, products, etc. further adds to the overhead in this area.	Stowing of consumables next to each other aids during inventory audits. Coordination among international partners is essential.	Crew Comments	86	Inventory, stowage
There was a lack of inventory management system onboard Mir. Each long duration crewmember preferred to use their own method of stowing items. The Russians have no established system and therefore moved items at will. The Russians would not provide detailed technical information, which would allow the U.S. side to develop accurate ground based computer or physical simulators of the Mir Station.	Affirmation of need for inventory management	Phase 1/MIR	5/36	inventory; IMS; stowage
An attempt was made to track GSE by kits composed of several pieces of equipment required to perform a particular function. The approach proved to be ineffective since in many instances the kits were delivered on a piece by piece basis. As a result, control and management visibility of the GSE were difficult until adoption of the more realistic approach of tracking individual pieces of equipment rather than groups.	Assemble kits only when all pieces are available. The CM overhead on partial kits is tedious and time consuming.	MSFC Skylab Lessons learned	2.5.4a	kitting, GSE, PHS&T
What label issues cost you time and why?	Stress importance of proper and consistent labeling	Crew Comments	3	Label

Colored labels were used on the CTBs to track bags returning and those going to Mir: pink for ascent and blue for descent.	Use of color coded labels to categorize cargo can be useful	Phase 1/MIR	3/14	label; packaging
Do you have any comments about the labeling of emergency equipment or emergency lockers?	Crew wants ‘time of usable air’ on O2 bottles in addition to amount remaining	Crew Comments	73	Labeling
Were there any identification labels that kept you from identifying hardware?	Stress importance that material labeling and procedure material identification match.	Crew Comments	70	Labeling, Maintenance
If the components of an assembly all had IMS barcodes label, was it difficult to determine which of the IMS barcode labels was the parent in IMS?	When components in an assembly had barcode labels it was sometime difficult to determine the parent.	Crew Comments	56	Labels, IMS
How much did you utilize the decals (i.e. O3, P1) located on the standoffs in the MPLM and US Lab? Would it be adequate (on future modules) to only label the rack bay (1,2,3) and have decals on the endcones indicating forward/aft and overhead/port/deck/s	Use a standard rack labeling scheme, use the Lab as an example.	Crew Comments	18	Labels, Stowage
Project budget bled by reliance on facility with small customer base and shifting NASA priorities	Stresses importance of supplier risk analysis	NASA PLL	1342	Lifecycle Analysis
Project underestimated complexity when using COTS navigation product in shuttle	Reinforces logistics role in overall systems engineering process	NASA PLL	1370	Lifecycle analysis
There is no systematic plan to counter obsolescence and assure the availability of adequate facilities, GSE, and specialized test-and-checkout equipment throughout the expected lifetime of the Space Shuttle.	Logistics should be responsible for providing a systematic plan to counter obsolescence and assure the availability of adequate facilities, GSE, and specialized test-and-checkout equipment throughout the expected lifetime of the Space Shuttle.	NASA PLL	1138	Lifecycle planning
Potential International Space Station (ISS) Supportability Problems With Existing Extravehicular Activity (EVA) Assets	Required logistics analysis to determine predicted lifecycle costs	NASA PLL	1144	Lifecycle planning
The funding of the EVA R&T program is not adequate to provide the maximum safety benefit in terms of new equipment and procedures that lower the risk of extravehicular activities	Required logistics analysis to determine predicted lifecycle costs	NASA PLL	1147	Lifecycle planning
The current and proposed budgets are not sufficient to improve or even maintain the safety risk level of operating the Space Shuttle and ISS	Logistics analysis required to draw conclusion	NASA PLL	1231	Lifecycle Planning
Elements of the Shuttle systems upgrades portfolio may be delayed or deferred necessitating a need to ensure adequate long-term **LOGISTICS** planning for mature systems	To make most cost effective decisions logistics analysis are performed.	NASA PLL	1232	Lifecycle planning

Apollo-era ground infrastructure for the Space Shuttle Program requires revitalization	Multi Program use facilities such as centers must perform continual logistics analyses to maintain capabilities.	NASA PLL	1233	Lifecycle planning
Strategic Resources Review (SRR) facility closure decisions	To make most cost effective decisions logistics analysis are performed.	NASA PLL	1234	Lifecycle planning
Insufficient amount of Simplified Aid for EVA Rescue (SAFER) units available for unplanned contingencies	Required logistics analysis to determine probability of sufficiency	NASA PLL	1113	Logistics Analysis
The current EMU is adequate for the near-term needs of the ISS and the Space Shuttle, but its obsolescent technology, high cost, and other limitations make it unsuitable for future exploration and development of deep space	Required logistics analysis to determine predicted lifecycle costs	NASA PLL	1126	Logistics Analysis
Parts Obsolescence May be Caused by Several Issues Including Vendors Going Out of Business, Discontinuance of a Part, and Environmental Law Changes	Contingency planning includes maintaining a priority list of top issues	NASA PLL	1013	Logistics program
Addresses Aviation Safety Assurance Panel (ASAP) concern regarding availability of Shuttle LRU spares	Required LRU forecasting and 'what if' scenarios	NASA PLL	1051	Logistics program
Transition and development of the LOGISTICS tasks for the orbiter and its ground operations under the SFOC are proceeding efficiently and according to plan	NASA and USA should continue the task of management integration of the formerly separate LOGISTICS contracts and retain and expand the roles of the experienced LOGISTICS specialists therein.	NASA PLL	1052	Logistics program
long-term projections are still suggesting increasing cannibalization rates, increasing component repair turnaround times, and loss of repair capability for the Space Shuttle LOGISTICS program	NASA and USA should reexamine and take action to reverse the more worrying trends highlighted by the statistical trend data	NASA PLL	1053	Logistics program
Process for reviewing MIR/Phase 1 lessons learned for applicability to ISS Program	Late stowage requirements for flights to MIR caused design of late load capability into the ISS Multi-Purpose Logistics Module (MPLM)	NASA PLL	1056	Logistics program
Components from a operational orbiter were removed to repair a non operational orbiter	Inadequate sparing causes cannibalization of orbiters to support launch	NASA PLL	197	LSA, Sparing
IUS design has no connectors, cables must be spliced	Maintainability assessment must include analysis of repairs that may occur during testing	NASA PLL	313	M&O

Do you have any suggestions on improving station hardware, station maintenance tasks?	Need to involve logistics standards early in design. Reduce number of and types of tools required.	Crew Comments	105	Maintainability
Excessive failure analysis time causes slow turnaround	Delays in accomplishing failure analysis causes excessively slow turnaround times for many repairable components	NASA PLL	221	Maintainability, Failure Analysis
For the location codes, would using an alternate color or increasing the label size make the label easier to locate/read?	Use of color codes for label criteria is acceptable	Crew Comments	57	Maintainability, labels
Logistics depot development	Establish a logistics depot	NASA PLL	220	Maintainability, SMR
Fiber-Reinforced Polymer Composite Material Selection	Reinforces necessity for creation, application, and enforcement of standards.	NASA PLL	689	Maintenance
Two individuals were left in manhole unattended	Lax attitude contributed to failure to follow procedures	NASA PLL	1085	Maintenance
In-orbit repair and maintenance can be performed satisfactorily in zero g. In-flight maintenance guidelines should include the following: 1. Consider extravehicular activity (EVA) as a normal means of repair. 2. Provide proper procedures, tools, and equipment for crew usage. 3. Design equipment to facilitate potential in-flight maintenance. 4. Consider EVA inspection and repair during the design requirements phase of a program. 5. Provide for the effective containment of nuts, bolts, washers, tools, hardware components, etc., by means of tool and/or retainer boxes, bungee cords, etc. 6. Provide for a worksite, repair bench, or equivalent equipped with adequate restraints for tools and equipment. 7. Provide spares for those hardware items most likely to require servicing and/or replacement. 8. Promote the use of standard-size screws, bolts, etc., in the spacecraft design. 9. Provide a high-fidelity maintenance training simulator. 10. Provide the capability to reservice fluid and gas systems from the interior of the spacecraft. Fluid/gaseous connectors (B-nuts, weld or solder joints) should be located and configured such that they can be inspected by the crew for leaks. ll. Design panels to allow replacement of	Design considerations for operations and maintenance	JSC Skylab Lessons	1-2	maintenance

indicator lights from the front of the panels. 12. Design external protective covers for experiments and other equipment for manual operation by EVA as well as by automatic opening. An EVA manual override may be necessary if automatic opening fails. 13. Single force fasteners should be used to close out all access panels in lieu of slotted or Phillips head screws.				
Routine maintenance of experiment hardware residing in Moscow was well planned and coordinated by PED/PI personnel. For example, routine GASMAP maintenance in Russia was planned and supported by PED personnel during the course of the program.	Operations and maintenance planning must include remote servicing activities if required	Phase 1/MIR	5/6	maintenance
What is your general impression of the serviceability and supportability of the station?	Identify equipment requiring service to designers so that convenient access can be instituted in design	Crew Comments	97	Maintenance
What's your general impression of the serviceability and supportability of the station?	Access panels need to be designed for convenient removal in operation environment. Specifically panels that require large amount of fasteners to endure launch loads may only require 2 to 3 fasteners in zero-g	Crew Comments	106	Maintenance
Protection of electrical connectors for GSE	Installation of appropriate electrical connector caps when not mated.	NASA PLL	850	Maintenance procedures
Provide a depot repair, maintenance, and modification capability for delivered experiment hardware. Schedule and manpower expenditures were minimized because of the quick turnaround capability afforded by the depot concept of operation and the physical location of the depot in relation to the receiving and shipping docks. The ability to repair items in the depot or to go directly to the proper specialty manufacturing area within the company greatly enhanced the time it took to achieve needed repairs. The members of the small team of people used to run the depot were all "graduates" of the qualification-acceptance test phases (engineering, test, and quality). This fact made the decision process more accurate and timely. Subsequent repairs and tests were accomplished more efficiently because of the experience of the personnel involved. The depot provided a suitable location for the mission support testing to assist in the	Depot staffed by experienced developers and located in proximity to operations provides timely repair activity and troubleshooting support	JSC Skylab Lessons	1-18	maintenance, depot

investigation of in-orbit anomalies during the Skylab missions.				
Initial design concepts should include in-flight maintenance provisions, with the necessary design features to facilitate failure detection, isolation, corrective action, and verification of repair. Provisions should be made for tools, spares, maintenance equipment, and space for maintenance work. Accessibility to equipment attaching hardware, electrical connections, and plumbing is imperative, even in areas where maintenance is not planned. All contingencies cannot be anticipated, but corrective maintenance action can be taken if the general design is consistent with this approach. In much of the unplanned Skylab repair work, it was necessary to remove cover plates held in place by an inordinate number of fasteners, which were not always of the design best suited for operational removal. Allen head screws and hexagon head bolts were much preferred over other types by the crew. A substantial effort had to be spent in identifying, to and by the crew, components, cables, and tubing to be repaired or replaced. A simple system of identification decals should be used to facilitate identification.	Initial design concepts should include in-flight maintenance provisions, with the necessary design features to facilitate failure detection, isolation, corrective action, and verification of repair. Provisions should be made for tools, spares, maintenance		2.6.1 Criteria for Design	maintenance, design for maintainability
Result of steam line accident mishap investigation board	No individual was responsible coordinating work	NASA PLL	1084	Maintenance, project management
Spares selection should include repair parts for critical items whose design permits in-flight bench repair, as well as replaceable assemblies. Skylab has proven that the crew, when provided the proper tools, procedures and parts, is capable of performing bench repair of failed assemblies beyond prior expectations. Although there were initially no repair parts aboard, these were provided on subsequent revisits and used successfully. A good example is the tear-down of tape recorders by the crew of SL-3 and the subsequent furnishing of repair parts and repair by the SL-4 crew. This reduced the volume requirements for resupply by providing a few repair parts instead of an entire new assembly. This philosophy could reduce the number of primary spares required on board initially, if the capability to repair the failed items is provided. Other examples of detail repair on Skylab	Crew can repair equipment to the lowest practical limit, regardless of SMR codes, provided that they have tools and parts.		2.6.3 Selection of spares	maintenance, spares

were the repair of the teleprinter and replacement of the printed circuit boards in the video tape recorder. The flight backup and test units on limited-production programs should be considered as spares sources within reasonable refurbishment effort, launch delay, and reprocurement time considerations.				
Did you have any problems with maintenance procedures?	Reinforces need for procedure and training standards.	Crew Comments	96	Maintenance, Standards
Tools initially selected for Skylab were primarily those required for specific tasks. A few contingency tools were included such as a pry bar, a hammer, and the Swiss Army knife, which proved to be valuable assets. Wrenches were provided only for specific applications. The crew activities and evaluation indicate a tool kit should contain all the tools normally found in a tool collection for comprehensive home usage, as well as the special tools required for special aerospace hardware. Good quality off-the-shelf hand tools are adequate and no special features are required for use in space. An improved tool caddy for carrying tools from place to place should be developed for easy location of the needed tool after arriving at the work station. Transparent material would be desirable. The caddy should also hold small parts in an accessible manner as the work is done, since containing and locating these items was a problem in zero gravity.	Include GP tools in toll kit. Facilitate transport of tools and securing of tools and parts in a zero g environment.		2.6.2 Selection of tools	maintenance, tools
Brakeline not connected on DC-X caused subsequent accident during recovery	Prototype design process did not place emphasis on development operations maintenance	NASA PLL	638	Maintenance; operation; documentation
Non-critical late changes to the manifest were accepted by the CCB without assessing the impacts to resources and schedules. These changes were primarily items requested by PEDs/PIs to cover potential contingency situations in flight (e.g., spare parts, back-up cables, additional logbooks, and disks).	There are many customers for the manifesting process, it is important to keep the controlling board(s) and the supporting logistics functions coordinated.	Phase 1/MIR	2-10.	manifest
Some payloads were not tracked by serial number, leading to uncertainty in which item was to be manifested for the mission and ultimately loaded onto the vehicle.	Not all material providers follow strict configuration management procedures; use of serial number tracked items permits an extra degree of granularity.	Phase 1/MIR	2/11	manifest

Too many nomenclature schemes were used to identify the same piece of hardware on different manifests. Drawing names, label names, crew names and Principal Investigator (PI) names were all used based on the needs/preferences of the user.	Despite previous experience in the identification and tracking of transported material, the operations community feels more comfortable with naming items than using part numbers and revisions	Phase 1/MIR	2-12.	manifest
PED/PI organizations were requested to provide the same manifest data to multiple manifesting organizations, creating the potential for inconsistencies between the data provided and taxing limited PED resources.	No enforced central repository for information causes the owning organization to supply the same information multiple times to different requesting organizations.	Phase 1/MIR	2/13	manifest
The manifesting of all Mir transfer hardware was controlled by the MOIWG and Phase I - the program drove the manifest, not the carrier. This eliminated an additional approval path through the Shuttle program and enabled Phase I management to establish priorities and effectively implement its science program.	If permitted, the transport vehicles will attempt to own the manifest process. Clear lines of control must be established and adhered to.	Phase 1/MIR	2-14.	manifest
Items sent to Russia for launch on Progress or Soyuz were prioritized by Phase I and/or MOIWG. This prioritization was particularly important because launch opportunities for U.S. payloads aboard these vehicles were uncertain due to mass and volume constraints. The prioritized list allowed the Russians to understand which items were critical for the mission and to plan accordingly.	It is a fact of life that manifested cargo will not be ready when needed or the vehicle will not have the published payload capability. To optimize the manifest process cargo will be prioritized and placed on standby.	Phase 1/MIR	2-15.	manifest
Multiple paths for manifesting payloads resulted in numerous disconnects in the manifest. Radiation Monitoring Equipment (RME), Extra-Vehicular Activity (EVA) and Med Ops payloads had alternate approval paths which did not supply the necessary manifest information to the MOIWG	A central controlling board must be established and publicized to prevent unrealistic expectations of material transport	Phase 1/MIR	2-16.	manifest
The lack of a controlled process for manifesting payloads aboard Progress or Soyuz led to difficulties in finalizing the launch manifests for these vehicles. Data was provided to the U.S. side only after the vehicle docked to the Mir and items were successfully transferred. In addition, a great deal of effort had to be expended to transport items to Russia with no guarantee that the items would ultimately get loaded onto the vehicle.	Manifesting processes tend to be vehicle and agency centric. A common process that ensures transportation access needs to be agreed to by responsible individuals in both organizations	Phase 1/MIR	2-17.	manifest

There was no clearly defined process to provide manifest inputs into the Phase 1 Requirements Document. As a result, some working groups or their supporting PED organizations established their own independent paths for manifesting payloads aboard Mir without coordinating with other working groups (ex: Extra-Vehicular Activities, Space Medicine Program, International Space Station Risk Mitigation).	If permitted, organizations supplying material to be transported will strike separate deals with vehicle providers.	Phase 1/MIR	2-19.	manifest
There were philosophical differences in manifesting between the Russian and U.S. sides. Russians had no established system by which they tracked launch manifests, resulting in an inability by the U.S. side to verify information in time to meet mission milestones. U.S. manifests are baselined at L-12 months, but Russian manifest information is not provided until after transfer on Mir.	Manifesting processes tend to be vehicle and agency centric. A common process that ensures transportation access needs to be agreed to by responsible individuals in both organizations	Phase 1/MIR	2-20.	manifest
Observation: Shuttle manifest changes are constant leading up to a flight. These changes occur due to science changes, operations, and problems that occur during long duration increments.	The greater the granularity of insight into manifested material, the more changes will occur as the flight matures. An open change process ensures that all parties are coordinated.	Phase 1/MIR	2-24.	manifest
A “below the line” manifest was maintained prior to freeze dates to identify additional payloads which might be added to the official manifest in the event a manifested payload had to be removed because of hardware failure or inability to meet schedules.	Not all material manifested for a flight is ready when needed. To mitigate this, NASA maintains a priority system and backup manifest to maximize transportation resources	Phase 1/MIR	2-7.	manifest; contingency
The same program level manifesting system should be used for every vehicle going to ISS. On the esoteric side. Ideally, the same manifesting system should be used for every vehicle going to ISS. Similar to an airline reservation system, if an item comes up with a requirement to be on the ISS by x-date, then a computer program could review the item’s development milestones and mass properties against the various launch vehicle flow requirements to find a potential launch vehicle.	Common manifesting system desirability. If not provided with a software application, owning organizations will develop their own apps.	Phase 1/MIR	2-1.	manifest; IMS;

The manifest was maintained in Russian and English on the same page, and used only metric values. Therefore, the manifest provided to the Russians via hardcopy was the same as that used by the U.S., which eliminated error associated with maintaining multiple versions.	When dealing with international partners, careful consideration must be given in establishing language and measurement standards. Although dual language and measurement capabilities were a concession, the impact on future transactions with other international partners were not considered.	Phase 1/MIR	2-6.	manifest; IMS
Observation: A great deal of time and effort is expended in manifesting items such as ziplock bags, tape, pens, dry wipes and paper. Recommendation: a. Set aside an area onboard station for stowage of common-use supplies. b. At a specified time prior to the next shuttle launch, have a crew person inventory the supplies on hand. C. On the ground, have a catalog of core pre-approved supplies that FEPC maintains to replenish those supplies. d. Remove these items from the standard manifesting process. Under the present system, it takes almost as much manpower to manifest a ziplock bag as it does to manifest a payload. Background: Any time the long duration crew needed these types of items, they had to be processed through the CR route. Drawings had to be changed, safety certifications generated and CCB approval obtained in the same manner that major hardware is processed.	Establishing and maintaining a qualified parts list will expedite the manifesting of materials on space transportation	Phase 1/MIR	2-3.	manifest; IMS; certification; loadmaster
Working Group 6 found it difficult to determine third-party (international) hardware ownership to obtain usage agreements. (ex. French camera)	Lines of ownership can become confusing as material passes through multiple providers.	Phase 1/MIR	2-32.	manifest; ownership
The trade-off between planning too many experiments and too few is very important. Processing reserve experiments would be very beneficial in the event that planned payloads drop out late in the process. However, even the planning process is expensive and PIs want to fly their experiments if they do the initial preparation.	Lower priority cargo may not be flown imposing significant operations and preparatory costs on supplying organizations.	Phase 1/MIR	2-35.	manifest; research

Component Terminology Simplicity and Consistency	Nomenclature selected for vehicle components should be simple, concise, and refer to common everyday terminology where possible (I.e. instead of calling a light a General Luminaire Assembly (GLA), call it a light). When complex terminology s used, it must be recognized that additional system familiarization and training for the crew and operational personnel are required. In addition, identical components should use the same terminology throughout the entire vehicle. Differences between engineering and operations nomenclature should be minimized.	John Commonsense	N/A	Nomenclature design
During recent Multi-Purpose Logistics Module (MPLM, S/N FM1) operations, some loose debris was generated by the Personnel Access Floor (PAF, S/N 002). The source of the debris was found to be from the personnel access floor rivets (Part Numbers MS21140 &	Design of GSE should include usage analysis to ensure product holds up under anticipated traffic	JSC Lessons Learned	369	outfitting, preparation for launch, PHS&T
Robust Systems Consumables	The overall system should be designed with sufficient consumable margins to accommodate foreseen contingencies. Lack of robust consumable margins requires very detailed design optimization that reduces mission flexibility and responsiveness to changing r	John Commonsense	N/A	overall system design
	Wherever possible, all circuit design and packaging of similar hardware or function will be standardized at the lowest possible level for supportability, maintainability, and interchangeability.	John Commonsense	N/A	Packaging design
Certification requirements should take into account the extremes of the ground storage and transportation and space environment. Hardware sometimes sat in cold warehouses.	Packaging specifications should identify the transport environment to the destination node. This must include all internodal transport to intended and potential vehicles.	Phase 1/MIR	3/5	packaging; transport

The process for packaging and processing CTB shipments to KSC was performed well due to well defined schedules and adequate lead times. The hardware was shipped directly to Spacehab and required good coordination between Stowage and Logistics.	Kitting can be delivered packaged for flight, providing that standards are followed.	Phase 1/MIR	3/12	packaging; transport
The Collapsible Transfer Bag (CTB) concept allowed greater flexibility for the ground and the crewmember for packing and transferring items.	The Collapsible Transfer Bag (CTB) concept allowed greater flexibility for the ground and the crewmember for packing and transferring items.	Phase 1/MIR	3/13	packaging; transport
Hardware packaging requirements were not compatible with actual transportation conditions in Russia. Thermal and shock loads encountered during transportation by rail or truck often exceeded the design capability of the shipping containers. In addition, the U.S. had no control over the mode of transportation within Russia.	Packaging specifications should identify the transport environment to the destination node. This must include all internodal transport to intended and potential vehicles.	Phase 1/MIR	5/10	packaging; transport
Crew Transfer Bag (CTB) packaging schemes were determined primarily by one specialist, resulting in a potential single point failure.	Logistics processing staffing must ensure capabilities are available when required.	Phase 1/MIR	3/2	packing; transfer; packaging
It has been noted through review of IMS data, that you have begun using the pantry concept for some items (bungies, tape, etc.). Any suggestions on how the stowage group can aid in the development/implementation of a broader pantry plan to include more l	Utility of pantry provisioning needs to be assessed and optimized for each application	Crew Comments	16	Pantry
Pantry-type food storage as opposed to meal-sequence food storage: Particularly for long-term flight, it is recommended that a pantry-style food storage system be implemented. In this type system, all identical foods are stored in the same location	Reinforcement of pantry stocking concept	JSC Skylab Lessons	1-5	pantry; provisioning; stowage
Delimitation of nozzles as a result of storage environment factors	Problem discovered during receiving inspection	NASA PLL	466	PHS&T
Circuit boards deteriorated during storage	Equipment doesn't always launch when scheduled, spares for launched systems may be used for other projects	NASA PLL	607	PHS&T
Monitoring spacecraft exposure to magnetic fields during storage and transportation	Space systems may be susceptible to damage from magnetic fields during storage or transportation and may require monitoring	NASA PLL	706	PHS&T

Maintenance & Test Criteria for Circuit Breakers to be performed prior to or during installation.	Pre-installation testing may be required for circuit breakers due to previous instances of process variables, inspection techniques, and even fraud	NASA PLL	848	PHS&T
During transportation of the X-33 fuel tank, the transport truck struck an underpass	Lead truck passed under overpass in center, transport truck did not follow exact track	NASA PLL	1068	PHS&T
Spacecraft damaged due to mismatch of spacecraft and GSE	Stresses importance of analysis and readiness reviews	NASA PLL	1089	PHS&T
Flight equipment not properly packed for shipment	Conflicting contractor and center PHS&T requirements result in confusion regarding correct configuration	NASA PLL	1211	PHS&T
Recipient of tool shipment refused delivery because tool was improperly packaged	Reinforces fracturization of logistics among organizations to the point where no entity is responsible for successful completion of task.	NASA PLL	1272	PHS&T
GSE interferes with installed payload in MPLM	Importance of design reviews and adherence to Interface Control Documentation	NASA PLL	1323	PHS&T
Closed cell material used for stowage restraints should have an allowable tolerance to account for changes in volume at different pressures.	Packing of materials transported through space must include a thorough analysis of encountered environments and effect on dunnage	JSC Skylab Lessons	2-7	PHS&T
Interface verification matrices should be established to ensure adequate fit checks of critical Government furnished equipment (GFE) hardware interfaces. A specific organization should be charged with the responsibility for generating and completing these matrices.	Regardless of analysis, reviews, certifications and qualifications, fitchecks to verify equipment mates will be requested. For equipment delivered packed for flight this may necessitate unpacking and mating unless it can be shown that the equipment was mated to other flight certified equipment.	JSC Skylab Lessons	14-1	PHS&T
Printed wiring boards solder connections have shelf life issues	Logistics support analysis must include shelf life analysis	NASA PLL	402	PHS&T, shelf life
Many of the orbital workshop equipment restraints appeared to be oversized. Simpler concepts would have probably saved cost, weight, complexity, and crew time. Operational equipment restraints should be standardized and should be simple and easy to use. Bungee-type restraints attached to stowage lockers, walls, doors, etc., would be adequate for many of the in-orbit equipment	Launch restraints are not used when equipment is on orbit	JSC Skylab Lessons	2-36	PHS&T, stowage

stowage and handling activities. Specific book restraints are needed at work sites to retain checklists and to keep them open to a given page. If a press-fit restraint is used for loose hardware, care must be taken not to insert the hardware too deeply or too tightly into the retention device. A specific means for keeping clothing spread out to dry while the crew sleeps would be desirable.				
Contaminated part sent to shipping	Tracking system must include special handling instructions	NASA PLL	99	PHS&T, Special Handling
Electrostatic precaution measures during ground processing	Reinforces necessity for creation, application, and enforcement of standards.	NASA PLL	685	PHS&T; marking
NASA budget reductions affect transitioned logistics functions	Budgetary squeezes increase cannibalization and component turnaround times	NASA PLL	1012	Planning, logistics program
General Crew Comment	Communications regarding the pre pack were beneficial in resolving questions	Crew Comments	65	Pre pack, communication
Discuss the role the ISS Loadmaster performed.	Transfer arrangement call for manned vehicle crewmember to be responsible for transferring cargo between vehicle and ISS. This person is designated as loadmaster	Crew Comments	85	Pre pack, Loadmaster, Transfer
The original plan was to discard the pre-pack list once the transfer lists arrived with the shuttle crew. Did this happen, or did you continue to use the pre-pack list?	Early crew used pre pack lists which did not always agree with final transfer lists	Crew Comments	59	Pre pack, transfer
Pre-flight processing and testing results in excessive mates and demates of flight connectors	Significant wear and tear occur to flight equipment prior to launch	NASA PLL	316	Pre-flight processing
Electrostatic Discharge (ESD) control in flight hardware	Reinforces necessity for creation, application, and enforcement of standards.	NASA PLL	732	Pre-flight processing
Integration and Test Practices to Eliminate Stresses on Electrical and Mechanical Components	Reinforces necessity for creation, application, and enforcement of standards.	NASA PLL	729	Pre-flight processing
Do you have any suggestions for us to make the pre-pack list and all the changes we send you easier to use? Would sending the same file back and forth and allowing the crew to insert comments and the ground to add new items be useful?	Commonality in packing and transfer lists	Crew Comments	9	Prepack, manifest
Did you ever reference the Station Flight X Transfer List prior to Station Flight X+1 arrival?	Reinforce need for coordination and commonality in stowage and transfer record identification.	Crew Comments	58	Prepack, Transfer

Fuel cells not properly isolated from shuttle electrical busses	Procedures did not address circumstances	NASA PLL	1184	Procedures
Quick Release Pin from gantry platform kickplate was found on shuttle	The less stuff you have that requires the use of QRPs the less QRPs you'll have available to get lost	NASA PLL	923	Procedures, Design for maintainability
Orbiter project is currently working to reduce the number of outstanding drawing changes	Reinforces necessity for performing obsolescence reviews and maintaining an active supplier surveillance program.	NASA PLL	1243	Procurement
Project difficulties due to inadequate budgeting, planning and engineering	Budgeted procurement time underestimate time to get vendors under contract	NASA PLL	1397	Procurement
Separate Center and contractor procurements of the same or similar items should be avoided, because this approach can result in several specification number or part number callouts for the same item. Common requirements for the same item by more than one Center or contractor should be coordinated, and the commonality aspects should be managed to the advantage of the program.	Separate Center and contractor procurements of the same or similar items should be avoided, because this approach can result in several specification number or part number callouts for the same item	JSC Skylab Lessons	5-3	Procurement, standards
NASA aircraft used for both Space Shuttle operations and astronaut training are increasingly out of date and, in several respects, may be approaching the unsafe	Logistics assessments required for cost benefit analysis for extension/replacement	NASA PLL	1102	Procurement/Planning
Design practices followed to make the Solid Rocket Boosters (SRB) reusable	Refurbishment and process improvements and their effect on lifecycle costs	NASA PLL	836	Product Lifecycle
Plans to fly Shuttle until 2012 necessitate phased upgrades to maintain schedules	Lifecycle improvements impact logistics support requirements	NASA PLL	999	Product lifecycle
Lessons learned from Chandra X-Ray Observatory Program	A good listing of programmatic lessons learned, see actual lessons learned section	NASA PLL	987	Program
Substantial Benefits to projects from use of Blanket Purchase Agreement (BPA) during procurement	Use of Blanket Purchase Agreement (BPA) during procurement allows flexibility during Indefinite Delivery/ Indefinite Quantity (IDIQ) contracts	NASA PLL	1218	Purchasing
AT by Accompanying Documentation (AD) was negotiated with the Russians to aid the processing of reflown payloads.	Vehicle specific flight qualification certifications must be established between vehicles, organizations, and agencies.	Phase 1/MIR	3/7	qualification; manifest; certification

There was a need for consistent definition of certification requirements for payloads. - Although certification requirements were defined in the 002 document, these requirements were always open to interpretation depending on the Russian specialist involved in the Acceptance Testing. - Russian and Shuttle certification requirements are different, thereby causing confusion PEDs. Russian requirements are general, whereas U.S. requirements tend to be specific. - Most problems were in fluid containment and verification and offgassing limits.	Vehicle specific flight qualification certifications must be established between vehicles, organizations, and agencies.	Phase 1/MIR	3/11	qualification; manifest; certification
Broken chairs are repaired under warranty	Maintain warranty records in event equipment does not perform as specified	NASA PLL	931	Record Keeping
As EEE components are processed and packaged original lot information is lost	Aerospace components have the added requirement for pedigree determination, lost information can cause non or loss of flight certification	NASA PLL	982	Record Keeping
Crane use even though out of operational configuration and past due servicing	Reinforces necessity for record keeping and maintenance planning	NASA PLL	565	record keeping; maintenance; operations
Checklist development of factors that affect long-term storage of devices	Reinforces necessity for creation, application, and enforcement of standards.	NASA PLL	684	Reliability; PHS&T
Poor weather visibility prevented technicians from adequately monitoring N2 tank filling	Operations procedures should be analyzed for all credible hazards	NASA PLL	871	Safety
Guidelines for close call reporting at GSFC are not clear	None other than as a participating organization	NASA PLL	1086	Safety
Vehicle launched despite abort directive	None other than as a participating organization	NASA PLL	1090	Safety
A 55-gallon drum of paint wastes subsequently ruptured after being over packed into an 85-gallon salvage drum due to leakage from the original drum	Reinforces handling procedures for transported and stored goods	NASA PLL	1181	Safety
Operators suffered extremity damage while performing work	None, other than as a participating organization	NASA PLL	1361	Safety
Uncoordinated work resulted in water deluge system activation	None other than as a participating organization	NASA PLL	1183	Safety, operations
Improper configuration of vehicle led to damaged fuel cell	Configuration not properly documented in repair procedures	NASA PLL	1182	Safety; procedures
Oil pumps were overfilled	Maintenance & Operations (M&O)	NASA PLL	216	Servicing

Ni-Cd battery handling and storage factors	Ni-Cd batteries can be damaged and irreversibly degraded through improper use and handling prior to launch	NASA PLL	644	Shelf life; issue processing; limited life
Super Ni-Cd battery handling and storage factors	Ni-Cd batteries can be damaged and irreversibly degraded through improper use and handling prior to launch	NASA PLL	694	Shelf life; issue processing; limited life
The shipping/logistics team developed a schedule and process for the return of U.S. hardware from Russia. To implement the plan, personnel were sent to Moscow to perform detailed inventories, review dual-language hardware lists with the Russians, determine which items would be transferred to RSA or Phase II, negotiate three-way protocols, and package the hardware for shipment. The efforts have resulted in the successful return of approximately $1.5 million of hardware, despite the numerous obstacles presented by RSA and Russian Customs officials.	The necessity of developing a end-to-end material lifecycle process is affirmed	Phase 1/MIR	5/15	shipping
The Russian organization structure required multiple levels of approval for hardware shipments. Personnel supposedly authorized to prepare documentation or approve shipments were unwilling to initiate a process without higher approval.	The necessity of developing a end-to-end material lifecycle process with empowered control gates is affirmed	Phase 1/MIR	5/18	shipping; manifest
Personnel hand carrying hardware into Russia were met with varying application of customs regulations based on the whim of customs officials. These items, as well as parcels sent through various express delivery companies, were more likely to be detained	The necessity of developing a end-to-end material lifecycle process with empowered control gates is affirmed	Phase 1/MIR	5/23	shipping; manifest
The standard shipping form (JSC 290) was created on a Macintosh software platform which was not available in PC format. This limited access to the form once PCs became the JSC standard desktop system.	Common software standards for forms and applications must be implemented prior to advent of operations	Phase 1/MIR	5/11	shipping; transport
The shipping template from JSC to Moscow (2 weeks) was not compatible with late changes to training, which required payload training hardware to be at GCTC.	Shipping of materials across international boundaries requires extensive lifecycle planning	Phase 1/MIR	5/44	shipping; transport
Having hardware facilitator/coordinators both in Moscow and the U.S. helps shipping, and tracking the hardware.	Use of expediters in foreign locations is justified when the amount of material shipped is extensive.	Phase 1/MIR	5/45	Shipping; transport

Many hardware shipping requests were not submitted in compliance with the shipping process. Inadequate lead times and incorrect shipping information provided by the requester resulted in rework of shipping forms and delays in the schedule. Some organizations opted to bypass the MOIWG entirely and ship/carry hardware on their own, resulting in unnecessary delays and additional costs.	If there is no coordinated approved process ahead of time, organizations supplying material to be transported will strike separate deals with transport agencies and organizations.	Phase 1/MIR	5/14	shipping; transportation
Organizational interrelationships on the Russian side were not properly defined, resulting in individual PEDs/PIs working directly with their Russian counterparts and/or special channels to deliver and process hardware.	If there is no coordinated approved process ahead of time, organizations supplying material to be transported will strike separate deals with transport agencies and organizations.	Phase 1/MIR	5/19	shipping; transportation
Sparing, Resupply, & Logistics strategy	Preposition spares to ensure mission success	John Commonsense	N/A	Spares provisioning
Sparing, Resupply, & Logistics strategy	Provide cannibalization options (component swapping due to failure or for system augmentation).	John Commonsense	N/A	Spares, swapping, provisioning
Russian spares philosophy is different from US. Russians do not use “new’ spares, they reuse old, or previously failed parts (cannibalize).	Inadequate on-orbit sparing may lead to cannibalization	Phase 1/MIR	5-2	spares; maintenance
Critical or multi-use hardware items needed onboard backups. Careful analysis is required for long-duration spaceflight impacts, e.g. impacts on electronics due to Single Event Upsets (SEUs). This list of critical or multi-use items requiring spares is typically outside the standard set used for Shuttle missions.	Initial lifecycle planning for some station components and payloads was based on a Shuttle model and did not take into account longer duration in a space environment	Phase 1/MIR	5/43	spares; maintenance; analysis;
Obsolete parts	Involves balancing the alternatives of purchasing and storage of excess parts, establishing manufacturing facilities and skills or potentially facing critical shortages	NASA PLL	222	Sparing and provisioning
As for the cargo stowage areas inside the compartments: do they hinder your work?	As the station is being built, there are open areas awaiting outfitting. Because not designated as a reconfigurable stowage location they are not involved in the stowage locations.	Crew Comments	78	Staging

At L-4 weeks, we uplinked a “Transfer Big Picture” message that included an overview of the items planned for return.	Crew liked the idea of early prepack coordination so that volume may be seat a side for stowage of large items	Crew Comments	84	Staging, Flight Arrival Preparation
As the construction of the Station progresses and more and more cargo is being delivered, is unloading cargo (MPLM, Middeck, Progresses) in staging areas, to be put away at a later time, still a viable plan?	Unused system areas, in this case the airlock, will be pressed into use for permanent and temporary stowage resources.	Crew Comments	17	Staging, stowage; Transfer
The LDM crewmembers often used the Progress and the CTBs as a staging area and worked from the bags directly instead of stowing items onboard Mir.	Transfer operations require a staging area to efficiently stow materials and cargo	Phase 1/MIR	3/15	staging; stowage; transfer
A staging area for Shuttle resupply was not defined. Therefore, each crewmember had to clear space to receive all packed bags. As bags were transferred to the Shuttle, resupply bags could be brought to Mir from the Shuttle.	Transfer operations require a staging area to efficiently stow materials and cargo	Phase 1/MIR	3/19	staging; stowage; transfer
We would like to continue doing the reverse audit (you only tell us what you need) for office supplies, and start including hygiene, six weeks prior to crew rotation when Shuttle flights resume, by sending the resupply form. Do you have any suggestions?	For many consumables, the crew may perform the inventory and provide the ground with the demand.	Crew Comments	95	Storekeeping
Do you have any suggestions on how the ground can better track consumable status while limiting the impact to the crew to provide the data? Our plan is to revise usage rates and resupply at the beginning of each increment.	Improve intra-ground communications. Use all available ground logistics resources before requesting additional data from crew.	Crew Comments	26	Storekeeping, Communication
Pre-packing of hardware on orbit is accomplished as tasks are completed and is typically not presorted. As a result, many categories of equipment may be packed in the same return bag; i.e. early destow science with R+3 and R+5 hour requirements, nominal destow items, crew personal items, GFE, etc. Destow operations are a complex and manpower intensive operation and need to be well organized to preclude loss of science and potential misrouting of hardware. As a result of early destow operations the "STS-81 U.S. Hardware Destow Ground Operations Process" (JSC-27665) was developed to formalize the Mir/Shuttle destow ground operations. However, this document does not control the organizations at KSC that deliver the hardware. Upon landing, hardware still may be returned from the runway by four different organizations,	The on-orbit crew packs the return manifest; a handful of individuals will accomplish the work performed by a hundred on the ground. It is important to plan and practice returned cargo dispositioning with all interested organizations and agencies.	Phase 1/MIR	6/4	stowage, pre-pack; manifest; staging

the shuttle flight crew equipment (FCE) personnel, the KSC payloads organization, Spacehab Inc. personnel, and in some cases, by VITT team members. These organizations deliver hardware to, respectively, the FCE lab at SSPF, the O&C high bay, the SPPF facility and the crew quarters. This makes inventory control a monumental activity. Each group operates using their own paper for defining requirements, e.g. the Launch Site Disposition Plan (Shuttle), the Phase 1 Destow Plan (Phase 1), Turnover TAP’s (KSC Payloads) and customer ICA’s (Spacehab), which are not necessarily recognized by other parties. Use the documentation plan as a model for future ground destow operations. A list of specific recommendations are included as highlights: 1. Establish a destow and inventory team, representing the operations organization (Shuttle) and the user organizations (Phase 1, (cut and paste error - see 6-5) ISS, Spacehab). 2. Hardware would be delivered to a central location for dispositioning and inventory control. 3. The requirements would be documented in one universally recognized destow document. 4. Alternatively, require the crew to pack all early destow and nominal destow items in separate bags (requires more space and crew coordination on-orbit). 5. Exception to the above rule is that cold stowage or other fragile items should be delivered to an off-line laboratory for processing by qualified personnel and inventoried on a non-interference basis. 6. Conduct a pre-landing meeting with the destow team members to ensure that all team members understand their duties and responsibilities. 7. Conduct a pre-landing meeting with the PED representatives to ensure that they are informed of potential turnover times and understand shipping requirements. 8. Ensure adequate PED support at Edwards in the event of a contingency landing. 9. Sort the Master Destow List several ways (by PED, bag, and part number) to meet the needs of the various destow operations. 10. Prepare preprinted labels containing hardware name and part number to facilitate the photography process for the descent				

hardware.				
Designers of onboard stowage facilities for future spacecraft should consider the following: i. Individual food stowage items should be located conveniently near the crewman's place in the wardroom. Spacecraft control panel numbers and stowage location	Stowage design considerations	JSC Skylab Lessons	2-6	stowage
Volume/space management for payloads within Mir was flexible enough to maximize module usage. Velcro, tethers, brackets or other devices could attach payloads wherever usable volume was available and crew safety would not be compromised. Constraining manifests by limiting payload accommodations would have resulted in fewer experiments.	Use of velcro and tethers within habitable space can create stowage volume.	Phase 1/MIR	¾	stowage
There were no established U.S./Russian Interface Control Documents (ICDs) or agreements citing stowage locations, allocations, or available nonstructural interfaces within Mir. It was believed that we had verbal agreements establishing the use of locations in the Spektr and Priroda modules that held U.S. hardware when the modules were launched. Over time, some of these locations were filled with non-U.S. items.	Coordination between organizations and agencies must be developed to the implementation level.	Phase 1/MIR	3/18	stowage
Stowage locations were not incorporated into the procedures. Stowage changes remained very dynamic throughout the program. Crew members usually stowed items in a manner to suit their needs and operational requirements.	It is necessary for procedures to reference accurate stowage locations.	Phase 1/MIR	3/20	stowage
Stowage Locations - Mir does not have dedicated stowage locations which greatly affects operations. This results in wasted time trying to locate items.	Configurable stowage locations must be included during vehicle development	Phase 1/MIR	3/21	stowage
Russians have a different philosophy on stowage planning and pre-launch stowage timing. Stowage needs extensive planning - especially for waste and used items. Removal of these items needs planning. Be prepared for late changes. Russians don’t do as much pre-flight contingency situation planning as we do.	Configurable stowage locations must be included during vehicle development	Phase 1/MIR	3/22	stowage

Any suggestions for improving communications and/or content of communications between on-orbit stowage planners and crew?	Some expedition crews wanted a more active role in stowing items. The “item location lookup” orientation of the IMS did not accommodate this. A key lesson learned is that the best stowage schema for transportation is not necessarily the best for user	Crew Comments	14	Stowage
Does the non-standard stowage have some negative impact to your operational efficiency or is there just no impact at all to the current non-standard stowage that you’re dealing with?	Stowage in general purpose workspace reduces availability of the space for other purposes	Crew Comments	8	Stowage
General Crew Comment	International partner participation in stowage activities is not guaranteed. In example cited 75% - 80% of equipment and tools in IP segment were found with prolonged search and consultation with other control centers.	Crew Comments	93	Stowage
To what extent would you say your work and every day activities were impeded by stowage on walls and in corridors? Do we need to add additional time to unstow cargo for any activities?	Item retrieval times are influenced by the amount of time it takes to clear path to access stowage area.	Crew Comments	107	Stowage
Were the crew provisions packed in an efficient manner?	Crew may restow items to meet crew peculiar needs.	Crew Comments	11	Stowage
Were the crew provisions packed in an efficient manner?	Crew recommends packing like items together.	Crew Comments	24	Stowage
What label issues cost you time and why?	All stowage locations should have the same location-labeling scheme.	Crew Comments	2	Stowage
During Shuttle flights an equipment list was built, replacement for daily stowage notes. Was the change in format confusing?	Do not change format of lists without training and informing crew.	Crew Comments	37	Stowage, Communication
Please indicate the top two habitability and human factors issues you experienced with ISS	Constant stowage flux affects housekeeping and quality of life.	Crew Comments	1	Stowage, Communication
How did the pantry style stowage work?	Pantry style stowage worked well	Crew Comments	67	Stowage, Crew Provisioning, Pantry
What suggestions do you have to minimize overall stowage inefficiency? How can the ground help to facilitate stowage consolidation and minimize large numbers of partial CTBs?	Daily consumption of food generates trash that must be disposed of.	Crew Comments	101	Stowage, excess, food

How did cargo and stowage management impact your mission?	Early IMS was inaccurate and difficult to use. Crew found it easier to have a daily listing rather than access IMS.	Crew Comments	4	Stowage, IMS
General Crew Comment	Reinforces necessity for periodic audits to synch the inventory to the IMS	Crew Comments	91	Stowage, IMS
Was an overabundance of stowage an impact to your time on-orbit?	Stowage discipline is the key to efficient use of time.	Crew Comments	6	Stowage, IMS
Pre flight we worked with the transfer folks to integrate our assembly procedures more into Work prep and the Transfer List and hope to streamline the process in the future. Do you have any comments on Work Prep, the Equipment List, IMS and the Transfer	Use of equipment lists are helpful and saves crew time	Crew Comments	12	Stowage, maintenance
	Crew will rearrange supplies as expedient during a mission. What seems to be a logical stowage scheme for the ground or a crew may be meaningless to another.	Crew Comments	103	Stowage, Pantry
Stowage Commentary	What seems to be a logical stowage scheme for the ground or a crew may be meaningless to another.	Crew Comments	27	Stowage, Pantry
Stowage Commentary	The initial estimates of time need to stow items are always too low.	Crew Comments	28	Stowage, Pre-Pack
Do you have any recommendations for items that should not be included in IMS?	Crew is mainly interested in IMS use for non-system inventory purposes. If an ORU is installed they are not interested in its location; it is part of the ISS assembly.	Crew Comments	33	Stowage, Storekeeping
Do you have any recommendations for items that should or should not be tracked in IMS?	There is a sort of Laffer Curve at work regarding storekeeping tasks in the crew workload. A realistic assessment must be made as to the smallest level of detail required to be tracked to effect a responsive logistics system as opposed to the lowest level	Crew Comments	108	Stowage, Storekeeping, Provisioning, Barcode
We are considering adding an “empty/full” field in IMS and on the BCR in a future version. We know that for items such as CTBs, CWCs, food containers, etc., that you were asked this a lot. Would this have been useful for you to use?	Add provision for crew to pack items into kit and then move entire kit.	Crew Comments	87	Stowage, Stowage, transfer, packing

General Crew Comment	Use of transfer packing item numbers on return bags is sufficient information, provided that the contents are tracked somewhere else.	Crew Comments	61	Stowage, transfer
General Crew Comment	The practice of tracking arrived supplies by when they arrived can be accomplished through use of color coded labels.	Crew Comments	64	Stowage, transfer
General Crew Comment	Transfer between shuttle and ISS is performed using Cargo Transfer Bags (CTB) as a result CTBs become the standard by which cargo is judged	Crew Comments	19	Stowage, transfer
How accurate was the ground's understanding of the on-board operational constraints associated with the management of stowage/cargo? (E.g., time to load/unload, staging volume).	Stowage and transfer is an evolutionary process, the early increments did not feel that the ground had a sound concept of the principles involved	Crew Comments	5	Stowage, transfer
Consumables' tracking was not established. An attempt to track consumables and hardware life was made during Increment 7, but because this required a methodical approach from the inception of the program, the effort was inadequate.	Affirms requirement for reasonable consumables tracking	Phase 1/MIR	5/28	stowage; consumable
Need multiple locations for critical and multi-use hardware items to reduce mission risk due to potential loss of these items if a particular module becomes uninhabitable (e.g., the Spektr incident).	A dynamic stowage system is flexible to accommodate loss of stowage volume	Phase 1/MIR	3/6	stowage; IMS
Kit contents were not tracked early in the program, creating problems with knowing where to find an individual item (such as scissors) and difficulty knowing how many items were still on board as the increments progressed. Individual contents were often returned not the whole kit. Starting with Increment 5, kit contents were tracked to provide insight into current stores of kit items.	Affirms importance of creating parent/child relationships when kitting	Phase 1/MIR	5/27	stowage; IMS
There was limited tracking of hardware items below kit level on the manifest. This led to difficulties in tracking piece parts on orbit and determining which items required resupply and which kits required refurbishment. As a result, unnecessary resupply items were approved and flown.	There is a complex relationship between manifests, inventory, and stowage that, if not understood completely, can drive data to excruciating minutiae that imposes a tremendous paperwork burden.	Phase 1/MIR	5/41	stowage; IMS; manifest

Hardware nomenclature should be standardized throughout a program. On Skylab, many names existed for a single item, and this nonstandardization resulted in confusion, ambiguity, and lost time during communications among various user groups.	Nomenclature issues will consume an inordinate amount of time. Establishment of standard to use name and part number in all labels, descriptions, procedures, etc. will mitigate this issue	JSC Skylab Lessons	12-1	stowage; label
The Dimensional Installation Drawings (DIDs) and Dimensional Sketches (DSs) did not go through the JSC release system because the drawing requirements agreed to in the US/R-002 document were not consistent with JSC requirements. In addition, the Russians reviewed the drawings in an open-ended iterative cycle, and there was no efficient way to release the drawings through the JSC system after each iteration without compromising mission milestones.	Configuration management between differing organizations and agencies must be coordinated using lifecycle objectives	Phase 1/MIR	3/8	stowage; packaging; transfer
Reflown items needed DID verification against the known module or station configuration since the configuration changed over time. However, since the Russian ground team did not have detailed knowledge of station configuration at any point in time, ground assessments using DIDs and DSs were often inconclusive	Configuration management between differing organizations and agencies must be coordinated using lifecycle objectives	Phase 1/MIR	3/9	stowage; packaging; transfer
The use of a Shuttle crewmember to assist in transfer, unpacking and locating hardware was extremely helpful to the LDM crewmember and to the ground in establishing the configuration for the next increment.	Use of transport vehicle personnel to transfer equipment optimizes resource loading and training	Phase 1/MIR	5/32	stowage; transfer
Every item flown to ISS should have an electronic picture available to the flight control team. Every item flown to ISS should have an electronic picture available to the flight control team. These images should not be on the main LANS or fileservers supporting the vehicle and flight controllers, but should be on a system that a flight controller could get to. The issue here is that LAN bandwidth can be impacted if too many positions begin reviewing too many images across the LAN at the same time. Each image should be accompanied by the relevant safety data, mass property data, flights manifested on, current location, etc.	Use photographs for every item of material manifested aids locating items on orbit. There is, however, a penalty associated with photographing, cataloging, and cross referencing each object. This LL is important when working with material delivered in a foreign language.	Phase 1/MIR	5/46	stowage; transfer; inventory

Design Commonality	Commonality should exist at the Line Replaceable Unit (LRU) subassembly level across all vehicles. By using common subassemblies across the vehicle, maintenance costs can be much lower as the need to assemble a wide array of spare parts lessens. This also reduces up-mass and on-board spares volume requirements. Commonality also reduces the number of hand tools that must be maintained onboard. The smallest number of different tools should be maintained on the space vehicle - for work both IVA EVA.	John Commonsense	N/A	Subassembly design
Interchangeability of Consumables	Consideration should be given to designing vehicle subsystems to that consumable items in common with other subsystems on the overall vehicle can be interchanged (I.e., S-IVB-stage pressurization and pneumatic He). The ability to transfer the fluids between the systems should be implemented.	John Commonsense	N/A	subsystems design
Component Removal and replacement	Systems should be designed so as to permit the easy removal and replacement of components. While in-flight replacement of malfunctioned units will not normally be a consideration for short mission space vehicle, it must be considered in the case of vehicle employed in missions of long duration. Replacement units should be located internally to expedite the replacement process. The following concepts should be considered in system/component design: a. Ease of maintenance (access, safing/hazard isolation, tool interface); b. Restrict pre-maintenance hazard isolation to item being maintained; c. Repair rather than replace; d. Replace at the lowest hardware level possible; e. Assume intermediate-level	John Commonsense	N/A	System/component design

	(LRU) subassembly) maintenance will be performed.			
The only trash disposal method identified on Mir was the use of the Progress vehicles. Incomplete information was supplied on items disposed of in the Progress.	Trash disposal manifests must be created to maintain an accurate on board inventory picture.	Phase 1/MIR	5/25	transport; manifest; trash; excess; stowage
As for the cargo stowage areas inside the compartments: do they hinder your work?	As materials are moved to/from from the transport vehicle, an ad hoc staging area is developed for temporary storage.	Crew Comments	78	Transfer
Do you have any suggestions for us to make the pre-pack list and all the changes we send you easier to use? Would sending the same file back and forth and allowing the crew to insert comments and the ground to add new items be useful?	Highlight changes in packing lists	Crew Comments	9	Transfer, manifest
To what detail would you prefer on-orbit stowage planners to be involved in transfer plan locations?	Communications are necessary to coordinate pre pack and identifying staging areas	Crew Comments	15	Transfer, prepack, staging, communications
To what detail would you prefer to see cargo transfer plans identify on-orbit stowage locations: A) Leave entirely up to the crew; B) provide specific locations for all cargo items being transferred; or C) provide locations only for items with specific	Communications are necessary to coordinate pre pack and identifying staging areas	Crew Comments	90	Transfer, prepack, staging, communications
The lack of real-time U.S. support at the Russian launch site prevented verification of the as-loaded list for Russian launches.	Other agency manifest processes may not ensure as-built documentation.	Phase 1/MIR	3/3	transfer; manifest
Logistics function is transitioning smoothly to Space Flight Operations Contract (SFOC).	Processes and procedures used in transition plan are effective	NASA PLL	1011	Transition
For some missions, it may be necessary for the Orbiter to land at the Dryden Research Center. These flights will be carrying science payloads, which require special handling and laboratory processing. Hardware off loaded at DFRC will have to be inventoried and turned over to a number of different experimenters. Facilities at DFRC are inadequate to perform these functions. The Mission management/WG6/Phase 1 office destow team has one office trailer available to receive, inventory, weigh, photograph and turnover the off-loaded hardware. On occasion, we have been asked to share this trailer with shuttle-sponsored payloads. No FAX capability exists and there is no water or restroom facility. Some lab capability is available at the PRF Facility, located several	Have a transport plan in place for the backup landing sites as well as the primary.	Phase 1/MIR	6/1	transport

miles away. The PRF is an ARC-owned facility and is not normally staffed unless ARC has payloads on board, except by special request. It is our understanding that this facility may be closed in the near future.				
The STS-76 mission landed at DFRC. Processing activities were a challenge, taking twice as long as KSC operations and 76 carried only a single Hab module. Had a fully loaded double Hab Shuttle-Mir Flight landed at DFRC, the available facilities would have been overwhelmed. Use of DFRC for ISS missions should be expected. Recommendation: Some minimal facility with adequate processing and laboratory space needs to be identified or constructed at DFRC for ISS use. The potential loss of long duration science would far exceed the cost of an adequate facility.	Have a transport plan in place for the backup landing sites as well as the primary.	Phase 1/MIR		transport
MOIWG had a dedicated shipping/logistics group with trained personnel and adequate resources to assume the responsibility of processing all hardware shipments within the NASA/Mir program.	Although each NASA site has a shipping/receiving unit, it is necessary to have a program specific function accountable for program assets	Phase 1/MIR	5-3	transport; handling; shipping
Shipping/logistics personnel coordinated well with program personnel and utilized all available resources to ensure success in shipping/hand carrying items to and from JSC. Communication with JSC Transportation, the NASA Travel Office, and PEDs/Payload Investigators (PIs) was well coordinated to identify potential couriers both to and from Russia.	Although each NASA site has a shipping/receiving unit, it is necessary to have a program specific function accountable for program assets	Phase 1/MIR	5/4	transport; handling; shipping
Shipping/logistics personnel took the initiative to stay abreast of all pertinent domestic and international import/export regulations. Contractor personnel recognized the need for such training independently and identified seminars and classes that would be beneficial (i.e., Export Control seminars conducted by the Bureau of Export Administration). JSC/JB7 identified similar needs at the same time.	Transportation functions must kept abreast of organizational and international export, import and shipping regulations.	Phase 1/MIR	5/5	transport; handling; shipping
The MOIWG shipping process for inbound and outbound shipments was developed early, and in compliance with JSC JB7 Transportation Shipping plans.	Although each NASA site has a shipping/receiving unit, it is necessary to have a program specific function accountable for program assets	Phase 1/MIR	5/12	transport; handling; shipping

An Integration Liaison was established in Moscow to assist with shipments and coordinate with U.S. Embassy personnel, Russian Customs and Russian Phase I personnel. The liaison was highly effective in establishing strong working relationships which contributed to the success in processing expedited shipments.	Although each NASA site has a shipping/receiving unit, it is necessary to have a program specific function accountable for program assets. This would include liaisons with foreign entities if traffic warrants it.	Phase 1/MIR	5/13	transport; handling; shipping
Shipping processes were developed based on State Department export regulations. While understanding of these regulations by shipping personnel matured over the course of the program, information on process, time, and cost was often ignored by hardware developers and those who developed the schedules. As a result, the MOIWG did not enforce strict compliance with the shipping process, and "smuggling" activity never met with disciplinary action due to the desire to meet schedules. Other related issues include the following: - Shipping considerations and constraints were not addressed in decision-making forums. The Configuration Control Board (CCB) Change Request review process did not include review by shipping/logistics personnel to verify that program schedules could be met. - The responsibility for hardware shipment was not fiscally tied to the MOIWG. All shipping costs were covered by JSC Transportation and were transparent to the MOIWG; as a result, the MOIWG had no appreciation for the labor and difficulties involved in expediting shipments, nor was there any financial oversight to manage the shipping function and impose accountability.	Transportation functions must kept abreast of organizational and international export, import and shipping regulations.	Phase 1/MIR	5/24	transport; handling; shipping
Hardware received from other NASA centers or private institutions did not have appropriate documentation which would qualify it for flight status (i.e., JSC form DD1149, COFR). As a result, these items could not be received formally into the JSC bond system until the correct documents were provided.	Different organizations, centers, and agencies have different standards. A program centric standard that applies to all material must be developed and in place prior to the advent of operations.	Phase 1/MIR	5/21	transport; handling; shipping; qualification; certification

All returning data products need to be identified in time to be incorporated in the destow documentation. As a result of the data from different experiments being recorded on common data recording devices, a general policy was established requiring all data products be archived at JSC prior to dissemination to the various experimenters. Some data products are unique to a specific experiment and cannot be duplicated.	Return cargo is subject to the same processes as launch cargo.	Phase 1/MIR	6/2	transport; manifest
The Destow Plan should be available electronically so that personnel needing it can receive it by email - or even via download from a web page. Destow Process. O&C vs. FCE. Hardware difficult to track down.	Ensure that return cargo manifests and dispositioning instructions are disseminated.	Phase 1/MIR	6/3	transport; manifest
Trash Management	Provide for immediate disposal of trash, rather than the stockpile method.	John Commonsense	N/A	Trash Management
The Russians kept all hardware left behind on the Mir and it did not seem that they threw anything away. This created cluttered conditions in the aisles onboard Mir.	It is important to understand need for all material on orbit and maintain a disciplined approach to stowage.	Phase 1/MIR	3/17	trash; stowage; disposal
Trash Disposal	Backup disposal provisions should be provided for all trash, garbage, food residue, feces, urine, etc., which could provide hazardous environmental conditions if the operational disposal system failed.	John Commonsense	N/A	Vehicle cargo, stowage design
Soft Stowage	Soft racks should be used for stowage (e.g. ZSR). Stowage locations should be easily accessible (one-handed accessibility), and locations should have dividers that are reconfigurable.	John Commonsense	N/A	Vehicle cargo, stowage design
Soft Bags 1	Soft bags should be designed to best fit soft stowage racks and hard stowage racks (I.e. payload or system racks) on the orbital station as well as stowage locations on the transport vehicle.	John Commonsense	N/A	Vehicle cargo, stowage design
Soft Bags 2	Soft bags should be available in various sizes (e.g. 0.5, 1.0, 2.0, and 3.0 CTB's, M-01 and M-02 bags)	John Commonsense	N/A	Vehicle cargo, stowage design

Stowage Locations	Design of all stowage locations should maximize available volume (I.e. locations depth should be as close to module shell as possible).	John Commonsense	N/A	Vehicle cargo, stowage design
Panel Front Stowage	Module panels should be designed so stowage may be located on the panel fronts throughout the vehicle for extended periods of time.	John Commonsense	N/A	vehicle design
Design and Component Compatibility	Commonality should be a prime consideration for all vehicle, system, component, and software in order to minimize training requirements, to optimize maintainability, reduce development and sparing costs, and increase operational flexibility. Special attention should be made to prevent failure propagation and allowances should be made for incorporation of system optimization. This extends to units of measure from design specification through system operation.	John Commonsense	N/A	vehicle design
Design the Vehicle for Maintainability	Assume that maintenance will need to be performed on any system. Manual interfaces should be easily accessible. Components should be designed so that maintenance tasks are simple. Panels should be designed so that any components behind the panel can be easily and quickly accessed.	John Commonsense	N/A	Vehicle design
Sparing, Resupply, & Logistics strategy	As much as possible, eliminate manual intervention to perform routine reconfiguration tasks. Provide additional level of FDIR software that performs 'BIT' functions for integrated systems and vehicles.	John Commonsense	N/A	vehicle design, reconfiguration
Transfer	Crew, passenger, and cargo transfer should normally be an intravehicular (IV) transfer operation. Design of the crew cabin must provide for efficient transfer and stowage of cargo	John Commonsense	N/A	Vehicle design, transfer operations, crew cabin design

On-orbit COTS	Usage of COTS products for on-orbit vehicles should be carefully weighed against the costs and risks of certifying and operating such products in a space environment.	John Commonsense	N/A	Vehicle hardware, components
During testing a 'banana plug' test connector contacted a ground strap, the subsequent arc tripped the circuit breaker	Existing stock of plugs in inventory were modified and impose requirements on new procurements	NASA PLL	985	Warehouse
The control of non-JSC tagged flight hardware through JSC bond pre and post flight was not well defined or understood. Numerous times flight hardware was delayed shipping to KSC/SPPF due to no records of certification even though the hardware was reflown hardware. Also, problems returning flight hardware once the Principal Investigator (PI) had completed data download was difficult requiring a new form 1149. ISS should have a process setup and separate bond room for ISS hardware that is shipped and controlled at JSC.	A program wide logistics plan and process must include center-centric processes	Phase 1/MIR	5/39	warehouse; transport
Hardware shipped from other centers to JSC was difficult to get into JSC Bond. Also, JSC quality rules changed for the paperwork requirements.	A program wide logistics plan and process must include center-centric processes	Phase 1/MIR	5/42	warehouse; transport
Flight articles need to have a designated bonded storage facility unique to program requirements to maintain configuration and quality control.	Strict access and configuration control is a must for equipment in storage and transit	Phase 1/MIR	5/38	warehouse; transport
Agreements with the Russians were made early to provide storage space at NITS, GCTC, and TsUP which would adequately accommodate the volume of hardware needed throughout the program. The storage space was not 'bonded' in a manner consistent with NASA centers. The rooms were secured only by a key which was kept by the building custodian. No safe, controlled storage facility for U.S. hardware was provided in Moscow, with the exception of Gagarin Cosmonaut Training Center (GCTC). Conditions at NITS were often detrimental to the hardware, and the volume of activity occurring at NITS with non-U.S. personnel made security a problem.	Warehousing and environmental requirements must be established prior to transportation	Phase 1/MIR	5/7	warehouse; transportation; packaging
Electronic Daily Products	Use of a integrated daily electronic product enhances accessibility	John Commonsense	N/A	

Sparing, Resupply, & Logistics strategy	The sparing, resupply, and logistics strategy should include development of quantitative dormant reliability parameters (probability that given component will operate as designed after a specified period of being inactive).	John Commonsense	N/A	
Sparing, Resupply, & Logistics strategy	Consider on-orbit fabrication of structural and mechanical replacement parts	John Commonsense	N/A	
Inventory Management	Long duration vehicles require capability to manage stowage and inventory including system configuration and compatibility (for swapping), and maps units to interior parts (for cannibalization). The capability should not require significant effort.	John Commonsense	N/A	
Tool Design	The smallest number of different tools should be maintained on the space vehicle - for work both IVA and EVA.	John Commonsense	N/A	
Tool Design #2	All tools should be certified for both IVA and EVA use so duplicate tool sets are not required.	John Commonsense	N/A	
Fastener Design	Establish common sizes of fasteners for components.	John Commonsense	N/A	
Tool Design #3	Develop no-tools-required replaceable components and access panels (especially for routine preventive maintenance).	John Commonsense	N/A	
Tool Design #4	Do not combine English and SI units (require the use of SI "metrics" sizes). Additionally, a tool set should minimize number of tools requiring calibration.	John Commonsense	N/A	
Battery optimization	Common usage batteries (for hand-held type devices) should be of a common type/design to maximize interchangeability. While not optimizing a battery to a particular application may reduce capability, providing a common set of batteries would reduce the amount of logistics and spares required while	John Commonsense	N/A	

	increasing operational flexibility.			
	Handhold attach points should e provided for handling large vehicle components. Also connections should be provided to permit breaking down large items to transportable size.	John Commonsense	N/A	

Appendix B: Survey Questions

1. To what degree have you observed the following in your work? To what degree would you recommend or agree with the use of the following?

Please select an option from each of the categories.

Observed						Recommend					
- Never	- Rarely	- Somewhat	- Frequently	- Often	- N/A	- Unnecessary	- Somewhat Unnecessary	- Neutral	- Recommended	- Strongly Recommended	- N/A

a. Design specification for stowage
b. The use of reconfigurable stowage
c. The use of pantry stowage (i.e. re-supply the pantry, not the individual items) for high turnover, small items
d. A naming and numbering system for stowage volumes
e. The consideration of cargo transfer operations when designing or configuring entryways or docking compartments
f. The use of an automatic inventory tracking system

2. To what degree have you observed the following problems, resulting from or relating to stowage difficulties?

a. Increased time demand for crew
b. Increased requirement for re-supply
c. Loss of access to operational space
d. Limits to housekeeping

- Never	- Rarely	- Somewhat	- Frequently	- Often	- N/A

3. To what degree have you observed the following in your work? To what degree would you recommend or agree with the use of the following?

Please select an option from each of the categories.

Observed						Recommend					
- Never	- Rarely	- Somewhat	- Frequently	- Often	- N/A	- Unnecessary	- Somewhat Unnecessary	- Neutral	- Recommended	- Strongly Recommended	- N/A

a. An inventory system common to multiple organizations
b. An inventory system based on a common logistics system
c. Configuration management using an inventory system that is common to multiple organizations and is based on a common logistics system

d. Packing lists and manifests used as manual accounting systems
e. Systems that update the movement and location of both parents and children in inventory with parent-child relationships
f. Inventory system that employs multi-level classifications of supply
g. Supplies with excessive inventory levels

4. To what degree have you observed the following in your work? To what degree would you recommend or agree with the use of the following?

Please select an option from each of the categories.

Observed						**Recommend**					
- Never	- Rarely	- Somewhat	- Frequently	- Often	- N/A	- Unnecessary	- Somewhat Unnecessary	- Neutral	- Recommended	- Strongly Recommended	- N/A

a. The use of commonality in vehicles, systems, or software
b. Minimized training requirements resulting from commonality
c. Optimized maintainability resulting from commonality
d. Reduction of development and sparing costs resulting from commonality
e. Increase operational flexibility resulting from commonality

5. To what degree have you observed the following in your work? To what degree would you recommend or agree with the use of the following?

Please select an option from each of the categories.

Observed						**Recommend**					
- Never	- Rarely	- Somewhat	- Frequently	- Often	- N/A	- Unnecessary	- Somewhat Unnecessary	- Neutral	- Recommended	- Strongly Recommended	- N/A

a. When designing for maintenance, the following are taken into consideration:
    i. tools
    ii. time
    iii. packaging
    iv. stowage
    v. lifecycle cost
b. Maintenance or repair system with multiple levels (ex. Operational-Intermediate-Depot)

c. Repair systems with scheduled corrective or preventative maintenance

6. To what degree have you observed the following in your work? To what degree would you recommend or agree with the use of the following?

Please select an option from each of the categories.

Observed						**Recommend**					
- Never	- Rarely	- Somewhat	- Frequently	- Often	- N/A	- Unnecessary	- Somewhat Unnecessary	- Neutral	- Recommended	- Strongly Recommended	- N/A

a. The design of return logistics with respect to:
    i. packaging requirements
    ii. pressurization
    iii. repairability/stowability
    iv. hazardous materials
b. Retention and storage of all waste
c. Off board discharge of waster
d. Classification of waste as retained or discharged

7. When designing or choosing transport modes for supplies, which of the following are taken into consideration, and rate their importance.

- None/Not considered	- Little Importance	- Somewhat Important	- Very Important	- Essential

a. Cost of various modes
b. Time
c. Quantity that can be carried
d. Materials/resources available

8. Rate the level of importance of each of the following.

- None/Not considered	- Little Importance	- Somewhat Important	- Very Important	- Essential

a. Design for stowage considerations
b. Design of an inventory system
c. Use of commonality in systems
d. Design for maintenance considerations
e. Planned use of standards in system development
f. Design for return logistics

8A. Rate the same characteristics according to their relative importance using a scale from 1-6, 1 being the most important and 6 being the least important.

__ Design for stowage considerations
__ Design of an inventory system
__ Use of commonality in systems

__ Design for maintenance considerations
__ Planned use of standards in system development
__ Design for return logistics

9. Are there more important logistics considerations that are problematic? If so, please explain briefly.

10. In response to prior experiences or lessons learned in your organization, in which of the following areas were logistics considerations taken into account?

__ Design for stowage considerations
__ Implementation of a common inventory system
__ Use of commonality in systems
__ Design for maintenance considerations
__ Planned use of standards in system development
__ Design for return logistics
__ Consideration of transport modes
__ Other: _____________
__ None

Appendix C: Survey Participants

Name	**Organization**	**Position**
Andre Goforth	NASA	Engineering
Benjamin S. Blanchard	Virginia Tech	Engineering
Bryan Austin	Boeing	Flight Operations
Charles Murphy	United Space Alliance	Logistics
Dave Garten	Honeywell Defense & Space	Engineering
Dennis Martinez	Boeing	Logistics
Donald Blick	Raytheon	Other
Elizabeth Pierotti	Honeywell-D&S Glendale	Logistics
Frank Camm	RAND	Other
James Visentine	Boeing ISS Logistics Support	Engineering
Jim Weisheit	BAE Systems	Program Management
Joe Parrish	Payload Systems Inc.	Program Executive
John Bull	Lockheed Martine Space Systems Company	Engineering
John Lauger	Boeing	Logistics
Kevin Wolf	Boeing	Logistics
Linda Patterson	Mission Ops-ISS Mechanics and Maintenance	Flight Operations
Martin J. Steele	Systems Engineering and Integration	Engineering
Michael Galluzzi	MK-SIO SSP	Program Management
Michael Ross	SMC/ISGL	Logistics
Olivier de Weck	MIT	Engineering
Richard Hicks	Orbital Sciences Corp.	Project Management
Robert Shishko	JPL	Engineering
Susan Voss	NASA JSC OC	Program Management
Sarah James	SOLE	Logistics
Sarah Shull	MIT/JSC	Logistics
Sean M. Van Andel	Boeing ISS Product Support	Engineering
Anthony Butina	NASA	Logistics
Terrence B. Johnson	Missile Defense Agency System Engineering Team	Logistics
Todd Hellner	NASA-ISS Program Office	Program Management
Tovey Bachman	LMI Government Consulting	Logistics
Ursula Stockdale	United Space Alliance	Flight Operations
Walter Tomczykowski	ARINC	Program Management
William A. Evans	Flight Operations	Logistics
William Robbins	NASA	Logistics
Anonymous	---	---

Appendix D: Additional Survey Results

Responses to additional survey questions are included below. Figure 17 shows that the transportation question regarding importance of various design considerations was inconclusive, since it showed little variation in the importance of considerations. Similarly, regarding possible problems arising from stowage difficulties, increased time demand for crew ranks number one, though there is little difference between the four options (Figure 18).

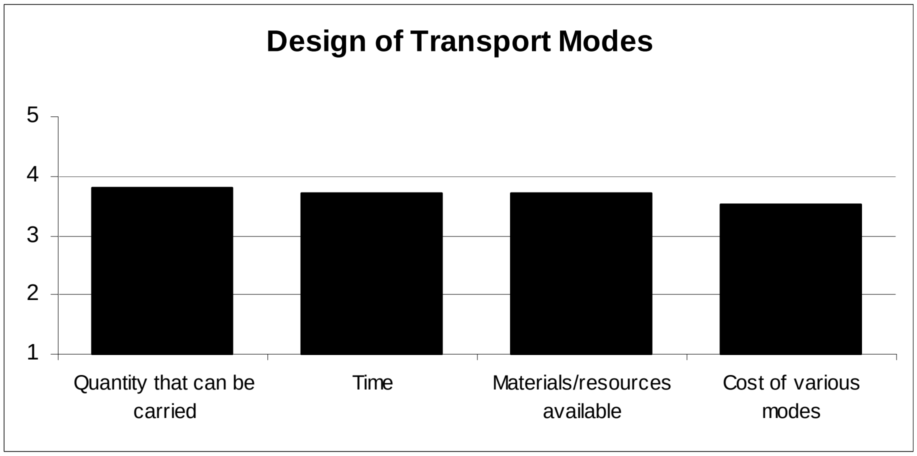

Figure 17: Transportation Decision Criteria

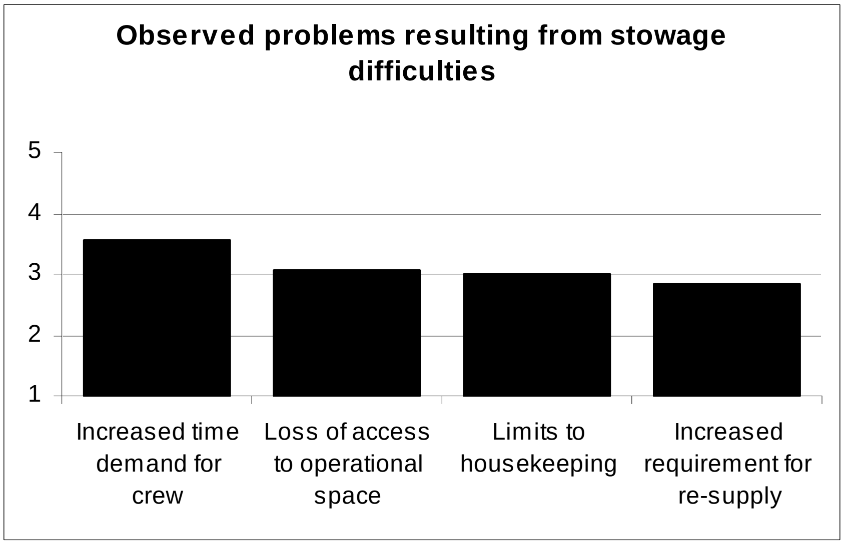

Figure 18: Stowage Observations

For the rest of the survey questions, participants ranked both their level of observation and recommendation of the various considerations. Where there is a large difference between *observed* and *recommend*, there may be opportunities for technology development or standardization to address the individual areas. This divergence also points to a need identified by the respondent where there may or may not be current mitigation to resolve the problem.

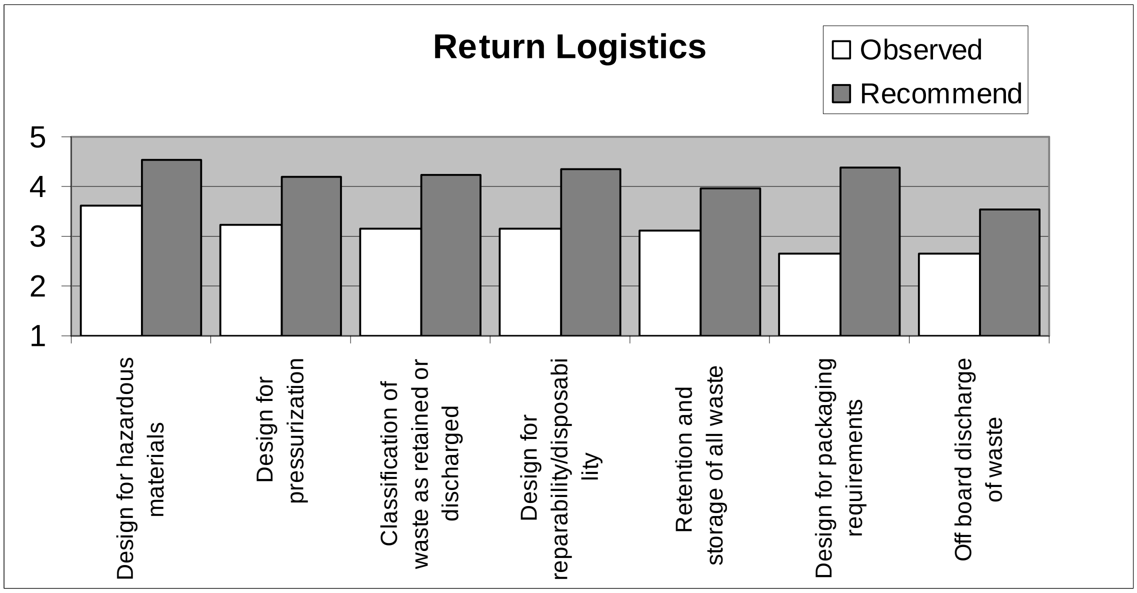

Figure 19: Return Logistics Considerations

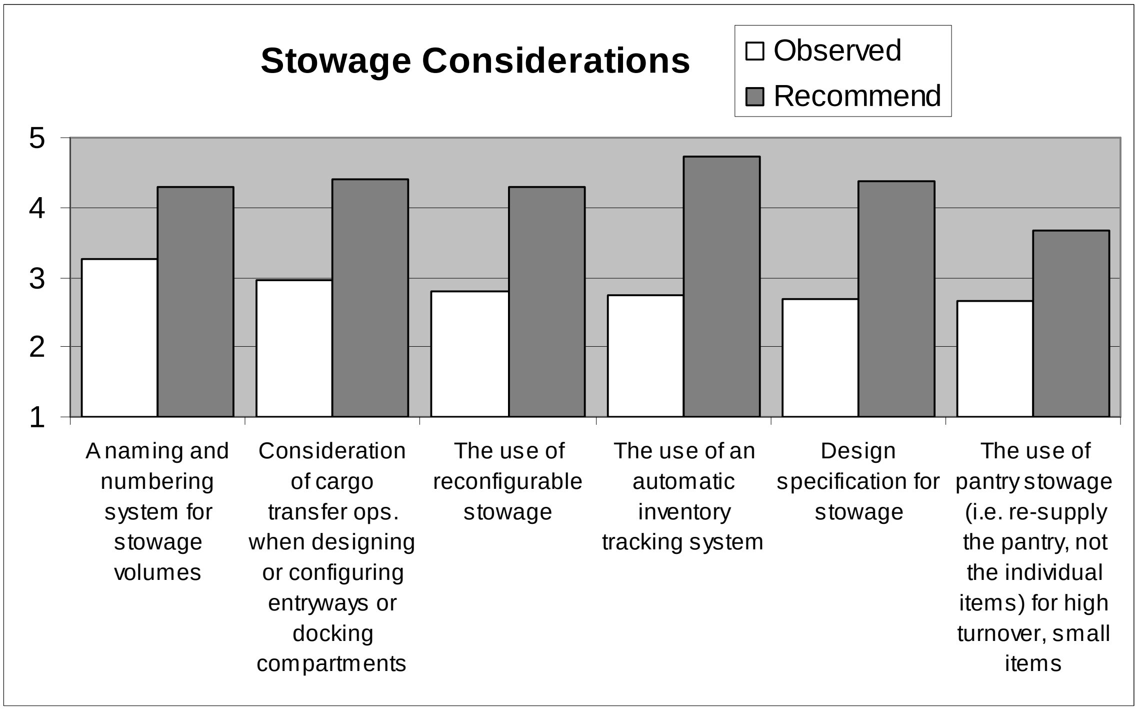

Figure 20: Stowage Observations and Recommendations

While Figures 19 and 20 do show evident differences between *observe* and *recommend*, these differences were found to be less significant that in other logistics areas, specifically commonality, inventory management, and maintenance. However, return logistics and stowage considerations are still prime candidates for future consideration when designing for logistics. Additionally, these charts present the opportunity to narrow the focus from *stowage* (Figure 20) to specific aspects of stowage of high importance, including *design specification for stowage* and the *use of an automatic inventory tracking system*. The survey results showing gaps between observed and recommended practices can be constructively used to identify specific issues in logistics where further measures can be taken.

Appendix E: Resources for Lessons Learned

Resource	Location	Search term(s)	Methodology	Date Complete	Product Developed
NASA Public Lessons Learned Database	http://llis.nasa.gov/llis/plls/index.html Publis Access http://www.nasa.gov/offices/oce/llis/home/new	Logistics	Using search terms 132 records were recovered. Relevant information cut and pasted into product file. Review interpreted information and produced summary	13 Jul 05	NASA PLL.xls
NASA Internal Lessons Learned Database	http://llis.nasa.gov/llis/llis/llis.html (Restricted Access)	Logistics	Spot checking of recovered records using search indicates same results as Public Lessons Learned database.	06 Jul 05	None
Crew Comments	http://mod.jsc.nasa.gov/dt/HTML/ECWGWeb/postflight/uspostflight.html (Restricted Access)	Logistics; packing; provisioning; IMS; Maintenance; stowage	IMT, MIOCB lessons learned and Crew Provisioning, Extra Vehicular Activity, Flight Crew Equipment/Food/Trash/Crew Provisioning/Habitation, Inventory Stowage Officer/Inventory Management System, Logistics and Maintenance, Prepack, and Stowage debriefs for 11 increments were reviewed and 108 comments extracted. Comments were sanitized and results interpreted as they apply to project.	14-Jul-05	Crew Lesson Learned.doc
JSC Lessons Learned	http://iss-www.jsc.nasa.gov/ss/issapt/lldb (Restricted Access)	Logistics	Using search term logistics, one record recovered. Same as PLL1205.	07 Jul 05	JSC #1
MSFC Skylab Lessons Learned	http://klabs.org/history/ntrs_docs/manned/space_stations/nasa_tm_x-64860_msfc_skylab_lessons.pdf (Public Access)	N/A	PDF file reviewed for logistics applicability. Relevant paragraphs cut and pasted into product file and keywords added. NASA Technical Memorandum X-64860	20 Jul 05	Skylab lessons learned.xls
JSC Skylab Lessons Learned	http://klabs.org/history/ntrs_docs/manned/space_stations/jsc-09096_jsc_skylab_lessons.pdf	N/A	PDF file reviewed for logistics applicability. Reviewed document and relevant paragraphs cut and pasted into product file and keywords added. NASA Technical Memorandum X-72920	20 Jul 05	JSC-Skylab.xls
FPPD Lessons Learned	http://eo1.gsfc.nasa.gov/miscPages/fppd-ll-database.html (Public Access)	N/A	Non searchable database containing 31 records, with last entry being 2001. Review of record titles does not identify any logistics applicable entries	20 Jul 05	None
EVA Lessons Learned	http://evaweb.jsc.nasa.gov/ccb/LessonsLearned (Restricted Access)	logistics	Search terms generated no hits. Reviewed each record for applicability and placed results in product	26 Jul 05	EVA Lessons Learned.xls

Resource	Location	Search term(s)	Methodology	Date Complete	Product Developed
Human Space Systems Operational Design Criteria Manual	http://mod.jsc.nasa.gov/Da8/exploration_vision/JOHN%20COMMONSENSE_JSC%2007268A%		Commonly referred to as 'John Commonsense' document (JSC 07268A). Review document for space logistics applicable passages	28-Jul-05	JohnCommonsense2.xls
Phase 1 Lesson Learned	http://iss-www.jsc.nasa.gov/ss/issapt/lldb/lldb_data/phase1lessons.doc	logistics	Each record reviewed for applicability and relevant items copied into product file and project applicability added	2-Aug-05	P1/MIR LL Extract.xls