The Future of Asset Management for Human Space Exploration: Supply Classification and an Integrated Database

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One of the major logistical challenges in human space exploration is asset management. This paper presents observations on the practice of asset management in support of human space flight to date and discusses a functional-based supply classification and a framework for an integrated database that could be used to improve asset management and logistics for future human missions to the Moon, Mars and beyond.

I. Introduction

One of the major logistical challenges in human space exploration is asset management. The International Space Station (ISS) program, for example, has experienced difficulties predicting spares requirements, tracking and storing tools and equipment, and gathering information on usage rates to enable shipment of appropriate amounts of crew provisions [1]. These difficulties are predicted to be significantly compounded for programs that venture outside low Earth orbit, where the complexity of manifesting and on-orbit tracking is even greater. It seems clear from past experience that sustainable space exploration operations are not possible without appropriate logistics tools for asset management.

The current state of the art in U.S. space logistics management for human missions is a series of databases that collectively manage the flow of information and goods for each mission. For instance, the parts catalog is maintained in one database, flight manifests are in a separate spreadsheet, on-orbit tracking of supplies is performed in another database and ground processing at Kennedy Space Center (KSC) is managed in yet another database or spreadsheet. The major fault with this arrangement is that there is very little, if any, interaction between these databases. This lack of interaction greatly increases the amount of human labor required for asset management and amplifies the chance of errors.

In support of future human space exploration missions to the Moon and Mars, personnel from the Department of Aeronautics and Astronautics at Massachusetts Institute of Technology (MIT) and the Jet Propulsion Laboratory (JPL) have developed an integrated database framework to handle end-to-end asset management and real-time tracking for such missions. This relational database, aptly named the Interplanetary Supply Chain Management

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(ISCM) Database, was developed as part of a NASA Exploration Systems Research and Technology (ESRT) contract and is intended to assist with asset management for several phases of human missions: pre-mission planning (such as spares requirements determination and demand forecasting), manifesting (including the parts catalog), on-orbit tracking (using Radio Frequency Identification (RFID) and/or barcodes), post-mission processing and integrated modeling. In connection with the database development, a set of functional classes of supply were developed based on existing NASA and military classifications. A prototype version of the ISCM database has been built in Excel© so that it can easily interact with SpaceNet a Matlab software code written to model the interplanetary supply chain [2]. The prototype database and supply classes have been field tested at a Mars analog base in the Canadian Arctic during the summer of 2005 [3].

Using the ISCM integrated database, a multitude of users ranging from astronauts to engineers to personnel in the mission control center could run queries on the information of interest to them. These queries will help users answer critical questions. Currently, the answers to these questions might require queries in several separate databases run by different teams. With an integrated database framework such as the ISCM database, all asset management queries can be made from a single source.

This paper presents observations on the practice of asset management in support of human space flight to date, presents a functional-based supply classification to be used for interplanetary logistics and discusses a framework for an integrated database that could be utilized to improve asset management and logistics for human missions to the Moon, Mars and beyond.

II. Current Practices

The current practice in U.S. space logistics management for human missions is a series of databases that collectively manage the flow of information and goods for each mission. As an illustration, consider the asset management scheme for a space shuttle flight to the ISS. Prior to the mission, personnel at Johnson Space Center (JSC) and Kennedy Space Center (KSC) are interested in assembling the manifest for the mission. To do this, they may need to access the parts catalog, which is maintained in one database. As they are building the flight manifests, they will be doing so in a separate database/spreadsheet. Once the mission launches, the on-orbit tracking of supplies is handled by yet another database and ground processing upon landing at KSC is managed in still another database or spreadsheet.

This example represents only a small portion of the logistics involved in operating the Space Shuttle and ISS but should point out the shortcomings of the current system, which 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 (SSP) or ISS Program that understands the entire process. Figure 1 below illustrates the interaction of just some of the numerous documents and databases that govern the Shuttle/ISS logistics flow.

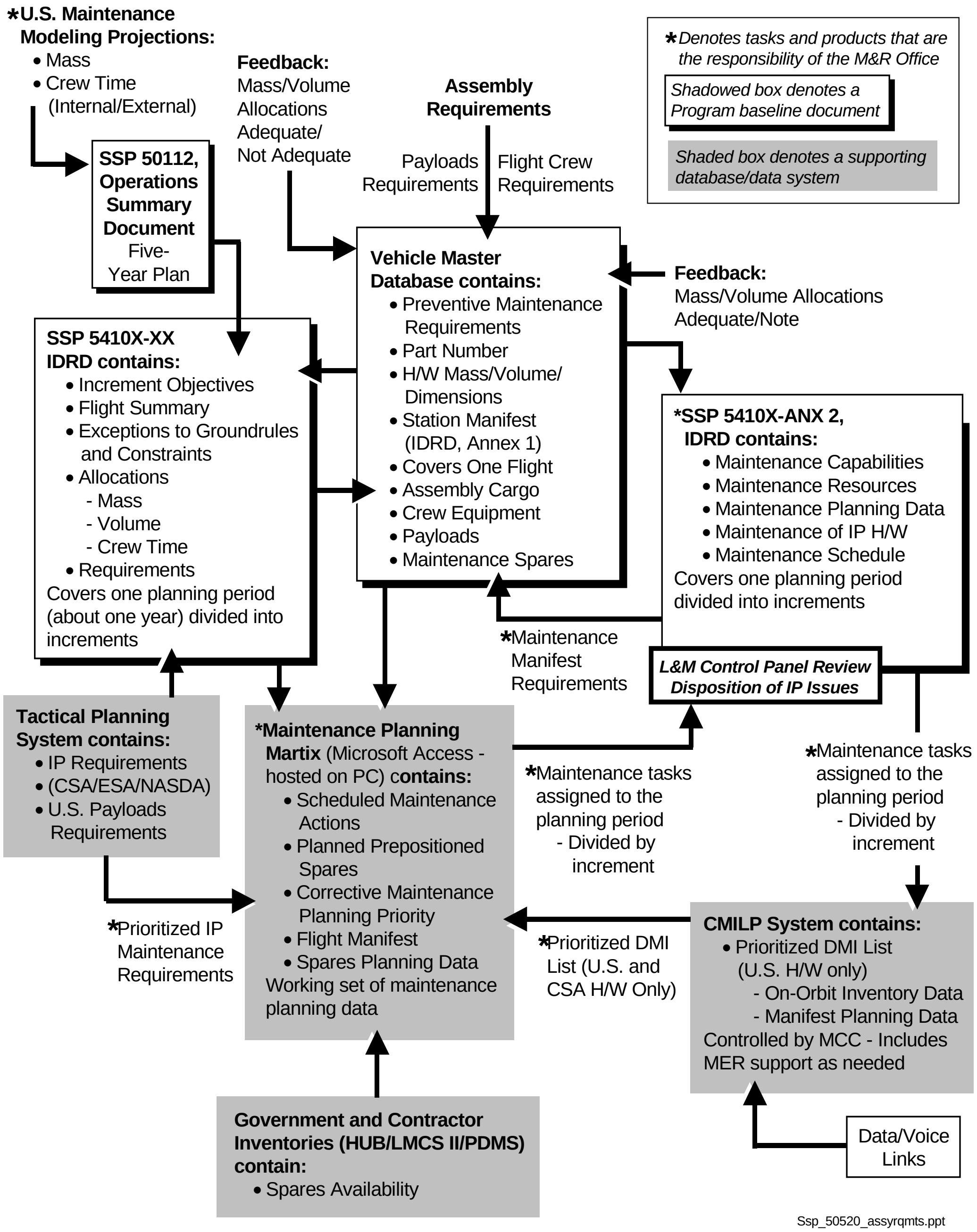

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Figure 1: ISS Support Planning Process [4]

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 execute 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 increases the chance that an error is made as data must be entered in multiple locations, often by different personnel.

The need for a unified relational database in also evident in ISS reliability and maintainability analyses, where the use of a flat file structure has led to persistent data anomalies such as missing data, inconsistent data, and SRU-ORU relationships that did not make sense.

III. An Integrated Approach

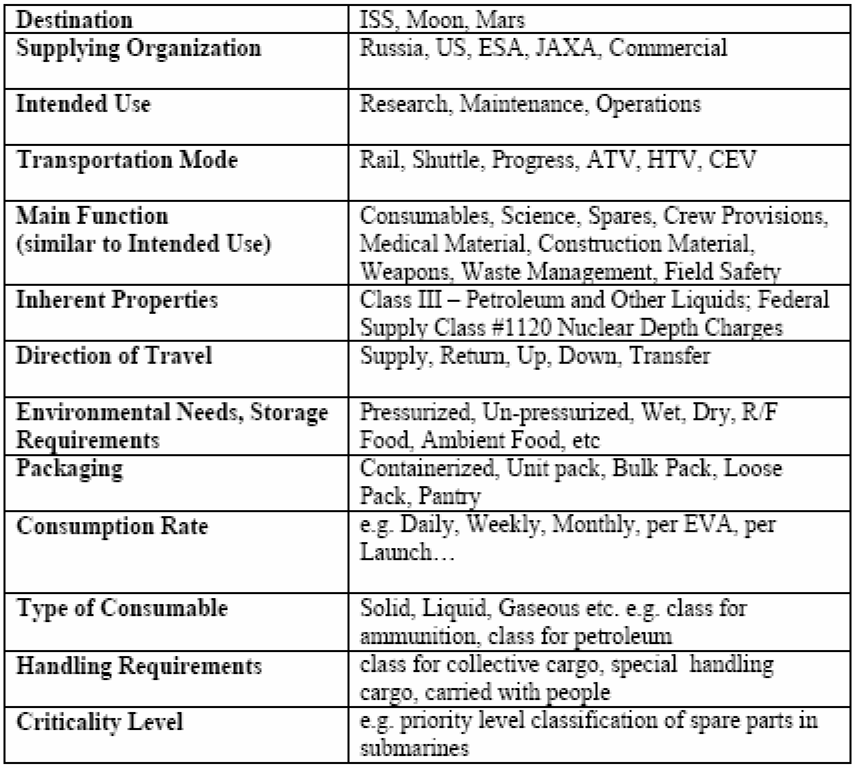
In the hopes of reducing the complexity and redundancy of information required in the asset management systems used by NASA for future human space exploration missions to the Moon and Mars, personnel from the Department of Aeronautics and Astronautics at Massachusetts Institute of Technology (MIT) have developed an prototype of an integrated database framework to handle end-to-end asset management and real-time tracking for these missions. The backbone of this effort is a relational database, aptly named the Interplanetary Supply Chain Management (ISCM) Database intended to assist with asset management for many phases of human space exploration missions including pre-mission planning (such as spares requirements determination and demand forecasting), manifesting (including the parts catalog), on-orbit tracking (using Radio Frequency Identification (RFID) and/or barcodes), post-mission processing and integrated supportability modeling. The benefits of this integrated relational database are to provide safeguards against unnecessary redundant data, data corruption during I/O, and inconsistent data relationships (false data),

This integrated database is not intended to replace all databases presently in use for mission planning and execution but instead strives to eliminate a portion of the redundancy of information and to raise accountability for asset and analysis data through strict configuration management practices. The following sections describe the framework for this relational database, starting with the development of a new supply classification to support asset management.

IV. Functional Based Class of Supply Development

A requirement of nearly any asset management system is a robust method of classifying your assets/supplies. Supply classification serves to collect logistics relevant items of a similar nature within groups with similar attributes. These attributes permit consistent management of supply items within a logistics system, including demand estimation and forecasting. A listing of common supply item attribute groupings is shown in Table 1. Imagine, as an example, the difficulty one would encounter in a supermarket if items were not grouped by food category (cereal, soup, bread, etc.) but instead were just placed at random on the shelves. Similarly, it seems that the success of an asset management system for human space flight would depend on the existence of a robust supply classification.

Table 1: Attributes for Supply Item Classification [3]



Destination	ISS, Moon, Mars
Supplying Organization	Russia, US, ESA, JAXA, Commercial
Intended Use	Research, Maintenance, Operations
Transportation Mode	Rail, Shuttle, Progress, ATV, HTV, CEV
Main Function (similar to Intended Use)	Consumables, Science, Spares, Crew Provisions, Medical Material, Construction Material, Weapons, Waste Management, Field Safety
Inherent Properties	Class III – Petroleum and Other Liquids; Federal Supply Class #1120 Nuclear Depth Charges
Direction of Travel	Supply, Return, Up, Down, Transfer
Environmental Needs, Storage Requirements	Pressurized, Un-pressurized, Wet, Dry, R/F Food, Ambient Food, etc
Packaging	Containerized, Unit pack, Bulk Pack, Loose Pack, Pantry
Consumption Rate	e.g. Daily, Weekly, Monthly, per EVA, per Launch…
Type of Consumable	Solid, Liquid, Gaseous etc. e.g. class for ammunition, class for petroleum
Handling Requirements	class for collective cargo, special handling cargo, carried with people
Criticality Level	e.g. priority level classification of spare parts in submarines

The obvious question then became, *does NASA have a robust supply classification that should be used for interplanetary exploration logistics* or will a new classification need to be developed? If one needs to be developed, do classifications exist in other fields that operate in similar environments? To answer these questions, a careful analysis was conducted of the classifications used by a number of organizations operating in remote environments such as the North Atlantic Treaty Organisation (NATO, see Table 2), the U.S. Military (Table 3) and the International Space Station (Table 4). Detailed comments are provided below, but it is interesting to note that classifications are inconsistent between organizations, primarily because different priority is given to the classification attributes (Table 1) and because mission needs are different.

Table 2: NATO Class of Supply [5]

Class	Description
I	Items of subsistence, e.g. food and forage, which are consumed by personnel or animals at an approximately uniform rate, irrespective of local changes in combat or terrain conditions.
II	Supplies for which allowances are established by tables of organization and equipment, e.g. clothing, weapons, tools, spare parts, vehicles.
III	Petroleum, oil and lubricants (POL) for all purposes, except for operating aircraft or for use in weapons such as flamethrowers, e.g. gasoline, fuel oil, greases, coal and coke. **(**Class IIIa - aviation fuel and lubricants)
IV	Supplies for which initial issue allowances are not prescribed by approved issue tables. Normally includes fortification and construction materials, as well as additional quantities of items identical to those authorized for initial issue (Class II) such as additional vehicles.
V	Ammunition, explosives and chemical agents of all types

Table 2 details the supply classification system used by NATO. From Table 2 table it can be noted that class I and III deal with consumables required for essential existence and operations (i.e. to support life), class V deals with consumables of the essential function (which is warfare), while class II and IV complement each other for everything else. This classification system appears to be largely based on how they are issued and intended use.

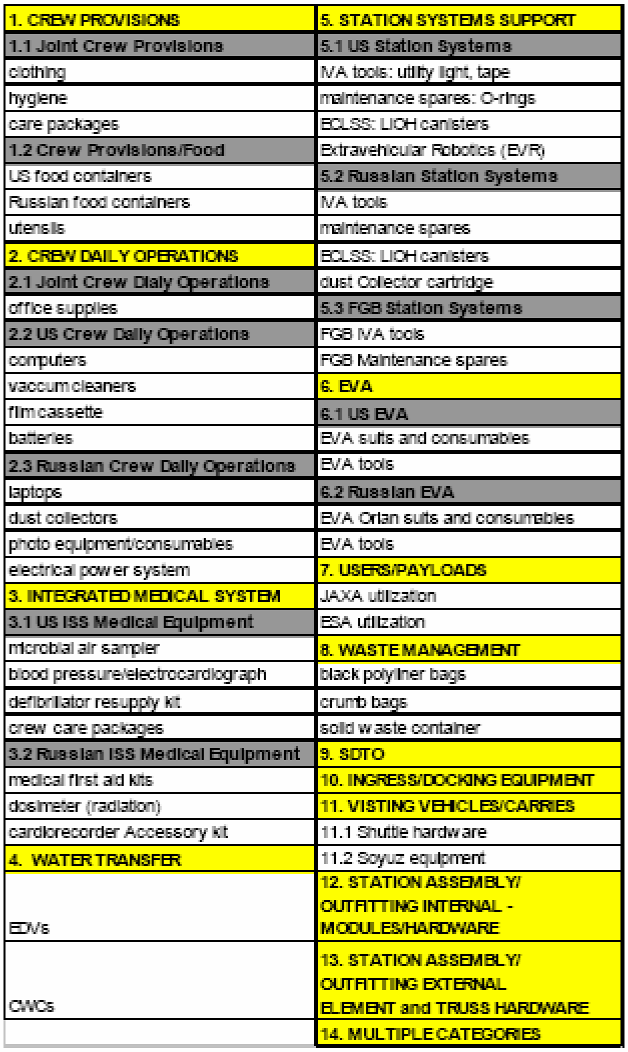
Table 3: U.S. Military Class of Supply [6]

Class	Supplies
I – Rations	Subsistence, gratuitous health and comfort items.
II – Expendables	Clothing, individual equipment, tentage, organizational tool sets and kits, hand tools, unclassified maps, administrative and housekeeping supplies and equipment.
III – POL	Petroleum, fuels, lubricants, hydraulic and insulating oils, preservatives, liquids and gases, bulk chemical products, coolants, deicer and antifreeze compounds, components, and additives of petroleum and chemical products, and coal.
IV – Barrier Materials	Construction materials, including installed equipment, and all fortification and barrier materials.
V – Ammunitions	Ammunition of all types, bombs, explosives, mines, fuzes, detonators, pyrotechnics, missiles, rockets, propellants, and associated items.
VI – Sundry	Personal demand items (such as health and hygiene products, soaps and toothpaste, writing material, snack food, beverages, cigarettes, batteries, and cameras—nonmilitary sales items).
VII – Major End Items	Major end items such as launchers, tanks, mobile machine shops, and vehicles.
VIII – Medical	Medical materiel including repair parts peculiar to medical equipment.
IX – Repair Parts	Repair parts and components to include kits, assemblies, and subassemblies (repairable or non-repairable) required for maintenance support of all equipment.
X – Material to support nonmilitary programs	Material to support nonmilitary programs such as agriculture and economic development (not included in Classes I through IX).
Miscellaneous	Water, salvage, and captured material.

Table 3 details the supply classification used by the U.S. Military. From Table 3 table it can be noted that class I, II, VI, and VIII relate to personnel (objects needed for their life and life-maintenance processes), with class I and VIII as the most critical classes followed by II and VI. Class III and IV are based on the type of material (work fluids, construction materials), class V are solid consumables of the essential function (warfare) and class VII are objects required for the essential function (warfare). Class IX is spare parts for all objects, so it has a general function of supporting the maintenance and repair of all equipment. There appears to be no consistent classification scheme in this grouping. Some classes are based on the type of material (e.g. class III), while others are based on type of function (e.g. class VII), and still others are based on the consumer/user of the objects (e.g. class I in which the personnel directly consume and use the items in this category).

For U.S. manned space flight, each NASA program has developed class of supply categories to be used in manifest planning, cargo planning, and stowage planning. The categories match up primarily with organizational structures and are different in each program. Since the operational requirements are different in the Space Shuttle Program (SSP) and the International Space Station (ISS) Program, integration has been problematic, resource planning has suffered, and the organizational structure has actually grown in both programs to cover communication between programs. On the ISS, a known system of supply classification is used, at least on the U.S. side. This system is referred to as the Cargo Category Allocation Rates Table (CCART). Table 4 reproduces the classification of cargo items on the ISS with some examples provided. It should be noted that this table lists all the top level categories but not all the sub-categories.

Table 4: ISS CCART [3]



1. CREW PROVISIONS	**5. STATION SYSTEMS SUPPORT**
1.1 Joint Crew Provisions	**5.1 US Station Systems**
clothing	IVA tools: utility light, tape
hygiene	maintenance spares: O-rings
care packages	ECLSS: LiOH canisters
1.2 Crew Provisions/Food	Extravehicular Robotics (EVR)
US food containers	**5.2 Russian Station Systems**
Russian food containers	IVA tools
utensils	maintenance spares
2. CREW DAILY OPERATIONS	ECLSS: LiOH canisters
2.1 Joint Crew Dialy Operations	dust Collector cartridge
office supplies	**5.3 FGB Station Systems**
2.2 US Crew Daily Operations	FGB IVA tools
computers	FGB Maintenance spares
vaccum cleaners	**6. EVA**
film cassette	**6.1 US EVA**
batteries	EVA suits and consumables
2.3 Russian Crew Daily Operations	EVA tools
laptops	**6.2 Russian EVA**
dust collectors	EVA Orlan suits and consumables
photo equipment/consumables	EVA tools
electrical power system	**7. USERS/PAYLOADS**
3. INTEGRATED MEDICAL SYSTEM	JAXA utilization
3.1 US ISS Medical Equipment	ESA utilization
microbial air sampler	**8. WASTE MANAGEMENT**
blood pressure/electrocardiograph	black polyliner bags
defibrillator resupply kit	crumb bags
crew care packages	solid waste container
3.2 Russian ISS Medical Equipment	**9. SDTO**
medical first aid kits	**10. INGRESS/DOCKING EQUIPMENT**
dosimeter (radiation)	**11. VISTING VEHICLES/CARRIES**
cardiorecorder Accessory kit	11.1 Shuttle hardware
4. WATER TRANSFER	11.2 Soyuz equipment
EDVs	**12. STATION ASSEMBLY/ OUTFITTING INTERNAL - MODULES/HARDWARE**
CWCs	**13. STATION ASSEMBLY/ OUTFITTING EXTERNAL ELEMENT and TRUSS HARDWARE**
	14. MULTIPLE CATEGORIES

From Table 4 one can observe that apart from the common categories such as crew provisions there are some that are based on a particular function (e.g. EVA, Payloads), some based on utility of material (e.g. waste management, which deals with all discarded/useless material), and some based on a specific material itself (e.g. water transfer); again the classification scheme is not logically consistent.

From this analysis it became apparent that a new formulation of the COS was required for interplanetary logistics due to the non-existence of any scheme that is suitable for interplanetary exploration. It was found that the classification schemes employed by NATO, the U.S. Military and NASA (for ISS) do not have a uniform way of categorizing the items in the supply chain. This inconsistency can be primarily attributed to the different mission needs of these organizations; each has a COS system customized for their particular needs. Even the most closely related COS, the Cargo Category Allocation Rates Table (CCART) used for ISS, had several deficiencies when exploration logistics in a larger context were considered. For instance, there are no categories in CCART that would allow for classifying propellants, habitation infrastructure, or surface exploration equipment. A new function-based generic COS classification was therefore formulated that would serve the requirements of an interplanetary exploration supply chain.

In order to formulate the functional based classes of supply, it was first necessary to identify the processes (functions) involved in an exploration enterprise. These processes could then be linked to their associated objects. Figure 2 shows the result of this formulation. In Figure 2 ovals represent processes (functions), while rectangles identify objects.

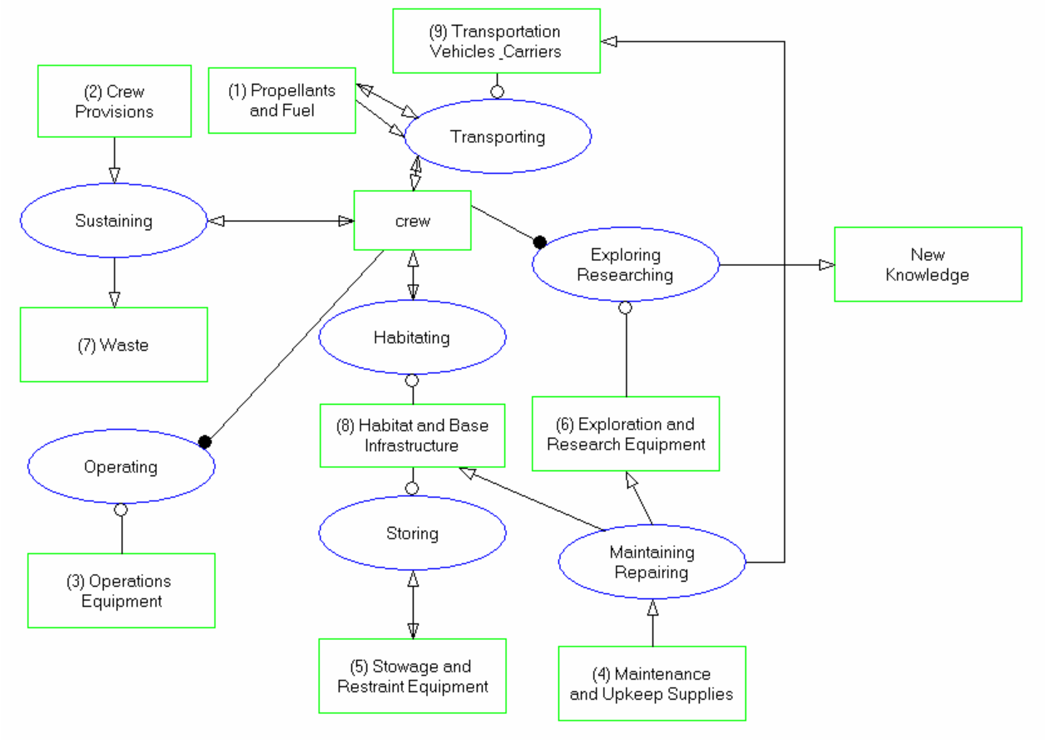


Figure 2: Object Process Diagram of a Generic Exploration System

Objects and processes are linked via affectee, consumee, resultee, and agent or instrument links [7]. Take as an example of this linkage for space exploration, a human crew exploring sites of interest to generate new scientific knowledge. This requires that the crew be transported there with transportation elements (vehicles and carriers), which causes consumption of propellants and fuels. Exploration and research equipment facilitates the process of exploring and researching. During the entire time the human crew must be sustained with various crew provisions (water, gases, food, medical supplies, etc.) which produce waste. For longer durations the crew must be sheltered in a habitat or larger ground infrastructure which often also consumes energy in the form of fuel. Inside this infrastructure provisions must be made for stowage/storage and restraint of various supply items. Operations equipment is required to allow the crew to communicate with the outside world, as well as properly monitor and control all systems on base. These systems must all be maintained preventatively or repaired in the case of failures to ensure safe and efficient operations of the exploration system.

Based on this analysis, a set of ten classes of supply was formulated, representing a high level grouping of the primary objects used in the exploration system. Figure 3 lists these classes of supply. Each of the ten classes has several sub-classes which further refine the categorization of the supply items. By assigning each item to a supply class and a sub-class, a multi-level supply class hierarchy is achieved which allows great flexibility when dealing with supply classes at different levels of granularity.

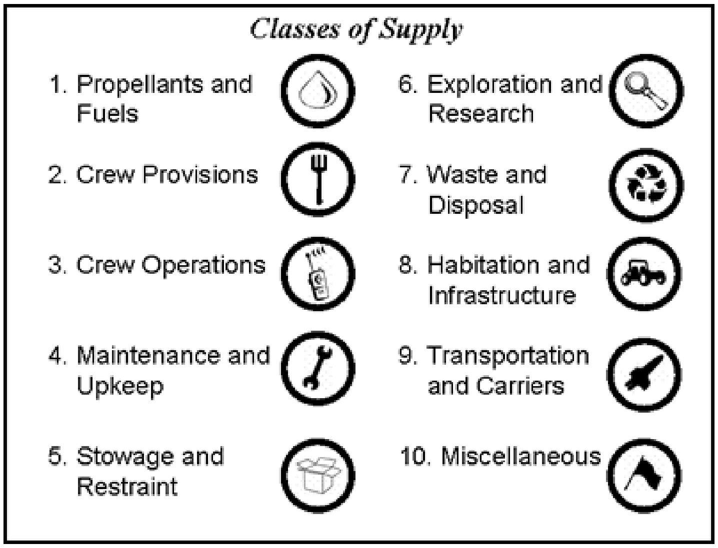


Figure 3: Functional Classes of Supply for Space Exploration

V. Class of Supply Validation

The first step of validation of this classification system was carried out by mapping the COS against the current taxonomy used by NATO, the U.S. Military and the International Space Station (CCART). The results of the mapping between the CCART system and the proposed functional classification of COS are shown in Table 5. The ten COS of the functional classification captures all major CCART items for ISS and adds a classification for propellants and fuels (COS 1), transportation vehicles such as ATVs (COS 9) and science and exploration equipment (COS 6) that would be used on a planetary surface as well as other items that might need to be provided in support of a remote exploration station.

Table 5: Mapping of Interplanetary Functional COS to CCART

Class	Sub-Class	CCART Category
1. Propellants and Fuels	Cryogens	
	Hypergols	
	Nuclear Fuel	
	Petroleum Fuels	
	Other Fuels	
	Green Propellant	
2. Crew Provisions	Water and Support Equipment	4
	Food and Support Equipment	1.2.1, 1.2.2, 1.2.3
	Gases	5.2.5
	Hygiene Items	1.1.3, 1.1.4, 2.2.4
	Clothing	1.1.2
	Personal Items	1.1.5, 3.1.4, 1.1.6, 1.1.1
3. Crew Operations	Office Equipment and Supplies	2.1.1, 2.2.2
	EVA Equipment and Consumables	6.1.1, 6.1.2, 6.1.3, 6.1.4
	Health Equipment and Consumables	3.1.1, 3.1.2, 3.1.3
	Safety Equipment	
	Communications Equipment	2.2.10, 2.2.9
	Computers and Support Equipment	2.1.2, 2.2.1
4. Maintenance and Upkeep	Spares and Repair Parts	5.1.2, 5.1.3, 5.1.4
	Maintenance Tools	5.1.1
	Lubricants and Bulk Chemicals	
	Batteries	2.2.6
	Cleaning Equipment and Consumables	2.2.3
5. Stowage and Restraint	Cargo Containers and Restraints	2.2.7
	Inventory Management Equipment	2.1.3
6. Exploration and Research	Science Payloads and Instruments	

Class	Sub-Class	CCART Category
	Field Equipment	2.2.5, 5.1.7
	Samples	
7. Waste and Disposal	Waste	8.2
	Waste Management Equipment	8.1
	Failed Parts	
8. Habitation and Infrastructure	Habitation Facilities	12, 13, 5.1.5, 5.1.6
	Surface Mobility Systems	
	Power Systems	
	Robotic Systems	
	Resource Utilization Systems	
	Orbiting Service Systems	
9. Transportation and Carriers	Carriers, Non-propulsive Elements	11
	Propulsive Elements	11
10. Miscellaneous		2.2.8
		2.11, 2.12, 2.13 will be distributed on an item specific basis in various categories

The second step of validation was performed during an expedition to the Haughton-Mars Project (HMP) research station on Devon Island in the Canadian Arctic. This expedition served to validate the functional view of exploration supply classes and ensured that a major class of supply had not been overlooked. While at the HMP research station, a complete inventory of the base was recorded. This involved documenting various attributes, including class of supply using the functional classification, for ~2300 items at the base. Physically recording a detailed inventory drove some refinement of the list of sub-classes to ensure that the list was complete, non-overlapping and reflective of the physical reality encountered at the HMP research station [3].

VI. The Integrated Database

In conjunction with the supply classification work described above, an integrated relational database was also developed to manage the asset information. A database is commonly understood to be a collection of related pieces of information (tables). A *relational* database, by definition, allows tables to be related by means of one or more common fields. In order to relate any two tables in a relational database, they simply need to have a common field, which makes the relational database model extremely useful [8].

In an attempt to improve asset management for human spaceflight missions to the Moon and Mars, a relational database for interplanetary exploration, aptly named the Interplanetary Supply Chain Management (ISCM) Database has been developed. This database incorporates inventory management capabilities with extensive capabilities for manifesting, spares requirements planning and mission planning. Information maintained in the integrated database includes astrodynamics data, element data, commodities data, spares data and node and arc data. (Note: In this model an element is defined as a major end item and includes launch vehicles, habitats, pressurized rovers, etc.) Table 6 below lists some of the most important tables in the ISCM database, along with a brief description of each and the intended usage of this information. It is important to reiterate that much of the value added in using a relational database is the fact that information need only be entered into the database once, eliminating the need for duplication of effort and reducing the chance that an error is made.

Table 6: ISCM Database Components

Table Name	Description	Usage
Supply Class	Attributes common to entire supply class (i.e. Crew Provisions)	Mission Planning, Manifesting, Real-Time Tracking
Supply Item Type	Attributes common to a supply item type (i.e. Printer Paper)	
Supply Item	Attributes specific to one instance of an item (i.e. Printer Paper Ream X)	
Element Type	Attributes common to an element type (i.e. Space Shuttle)	
Element	Attributes specific to one instance of an element (i.e. Atlantis)	

Table Name	Description	Usage
Crew	Attributes specific to one crew member	
Supply Item History	Maintains a history of changes in data for each supply item	Real-time Tracking
Element History	Maintains a history of changes in data for each element	
Crew History	Maintains a history of changes in data for each crew member	
Astro	Astrodynamics Data	Mission Planning
Physical Nodes	List of Nodes	
Arcs	List of Allowable Arcs between Nodes	
Crew Provisions	Usage rate data for each supply item defined as crew provisions	Manifesting Real-time Tracking
Crew Operations	Usage rate data for each supply item defined as crew operations	
Parts Common	Common (i.e., regardless of application) data (e.g., function) for spare parts	Spares Requirements Planning, Manifesting
Parts Application Specific	Application-specific data (e.g., MTBF) for spare parts	
Maintenance Tasks	Specific maintenance task for each parts application	
Task Resource & Time	Resources required (crew, robotics, etc.) to perform a specific maintenance task	
ORU-SRU	ORU-SRU indenture data	

A prototype version of the ISCM database has been built in Excel so that it can easily interact with the SpaceNet Matlab software code written to model the interplanetary supply chain. (Details of the modeling of the interplanetary supply chain are described in [2].) Version 2.0 of the ISCM database, to be released in 2007, will be coded in SQL, with a JAVA user interface.

Figure 4 displays a representative portion of the ISCM database structure. This figure illustrates the relational nature of the database. The fields in yellow represent the table "key". A table key serves to uniquely identify items in the table. The relational aspect of the database can be seen in the linkages between the tables. As an example, the black arrow in Figure 4 points out the common field between the *Supply Type* and *Item* tables, the "Supply Type ID". By associating a certain Supply Type ID with an item, all of the attributes associated with that Supply Type ID are automatically also associated with that item, without the user having to enter any duplicate information.

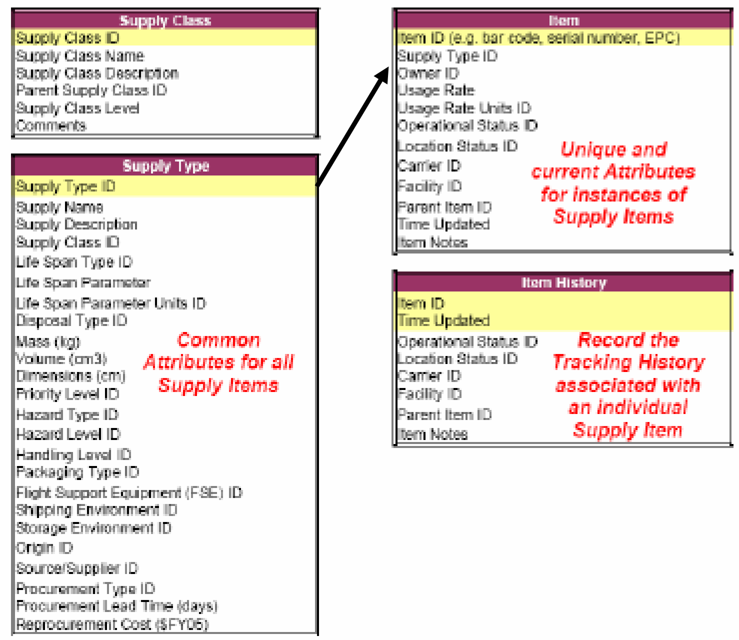


Figure 4: Sample of ISCM Database Structure

Also shown in the figure is the hierarchical database structure for supply items, starting with the supply class (i.e. Crew Provisions), moving to the supply type (i.e. Printer Paper) and finally to the individual instance of an item (i.e Printer Paper Ream X). All past transactions of each individual item are captured in the Item History fields. Similar hierarchical structures exist for habitation elements (e.g. lunar surface habitat) and transportation elements (e.g. CEV or lunar lander). For each commodity (supply item) or element (habitat, launch vehicle, etc) tracked in the integrated database numerous attributes are recorded. Figure 4 illustrates the types of attributes associated with each commodity in the database. From this figure, it should also be noted that the database is structured such that a time history is always maintained of each element/commodity.

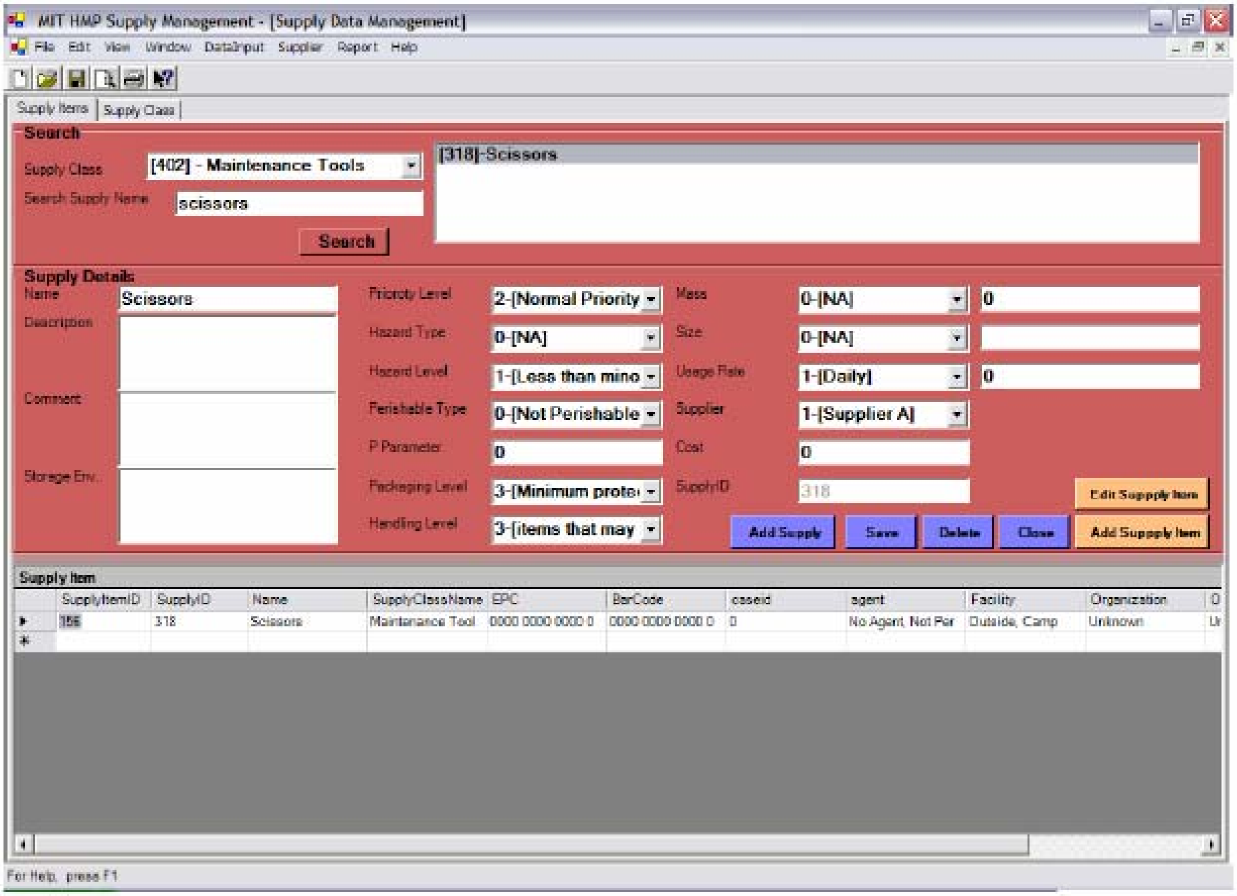
The integrated database seeks to serve the needs of a variety of users including astronauts, mission controllers, ground processors, and loadmasters. Using the integrated database this diverse group of users is able to run queries to answer questions relevant to their area of interest. For example, for the Inventory and Stowage Officer in the Mission Control Center in Houston (MCC-H), these questions could include:

- Where is a supply item ‘X’ now?
- What’s the current status (expired, failed, etc.) of this item?
- Where has the supply item been?
- What’s the usage rate of a certain supply type?
- How many supply items are at the research station?
- How many supply items of supply class type ‘Y’ are at the research station?
- Find all the supply items with less than ‘#’ units at the research station?

Currently, the answers to these questions might require queries in several separate databases run by different teams, yielding potentially conflicting answers. With an integrated database framework such as the ISCM database, all asset management queries can be made from a single source.

VII. Integrated Database Validation

The prototype database and supply classes were also field tested at the Haughton-Mars Project (HMP) Research Station in the Canadian Arctic during the summer of 2005 [3]. Prior to arriving at the HMP research station, the framework for a relational database to support the management and analysis of asset (supply) data at the base was developed. This database was built using SQL Server 2000. Figure 5 shows a snapshot of the user interface to this database. During preparation for the HMP expedition, it was found that logistics (i.e. supply class) information needs to be organized and presented in ways that are tailored and customized for particular classes of users. It would be a mistake to create a hierarchical database that presents only a single view. Rather, the use of a relational database structure allows customized reports for the various stakeholders involved in space exploration logistics: Astronauts, Mission Operators, Load Masters, Procurers/Vendors, and Logistics Modelers. The database allows the user to search for an item by supply class or supply item name. All the attributes associated with each item, such as mass, size, priority level, etc. are captured in this database. Figure 5 shows the structure of the SQL Database and all the attributes that the database is capable of capturing.



Supply Class: [402] - Maintenance Tools
Search Supply Name: scissors
[318]-Scissors

Name: Scissors
Description:
Comment:
Storage Env.:
Priority Level: 2-[Normal Priority
Hazard Type: 0-[NA]
Hazard Level: 1-[Less than mino
Perishable Type: 0-[Not Perishable
P Parameter: 0
Packaging Level: 3-[Minimum prote
Handling Level: 3-[items that may
Mass: 0-[NA] 0
Size: 0-[NA]
Usage Rate: 1-[Daily] 0
Supplier: 1-[Supplier A]
Cost: 0
SupplyID: 318

	SupplyItemID	SupplyID	Name	SupplyClassName	EPC	BarCode	caseid	agent	Facility	Organization	O
▸	156	318	Scissors	Maintanance Tool	0000 0000 0000 0	0000 0000 0000 0	0	No Agent, Not Per	Outside, Camp	Unknown	Ur
*											

Figure 5: HMP Integrated Database Graphical User Interface (GUI)

To support an automated asset tracking capability, an expanded database was created that also captures the various locations, transportation vehicles and agents (individuals) that are involved with the research station. The database was designed to automatically record changes in the *location status* of any supply item that entered or left the research tent (or mess tent during agent tracking) by reading data from the Radio Frequency Identification (RFID) readers located at the entrance to a tent. (Tents at HMP are the equivalent of habitat modules on a Lunar or Martian base.) The location status is reflected in the bottom half of the database, under the 'Supply Item' and `Supply Item History' headings. Of the 2300 items that were inventoried at HMP, approximately 1900 of these items have been entered into the HMP SQL database. It is now possible to query the database to get important information on any supply item.

VIII. Conclusions

From this work two primary conclusions can be drawn:

1. The functional classification for space exploration supply classes proposed in Figure 3 and validated at the HMP Research Station is a robust high-level classification, independent of organizational boundaries and specific supply item or mission requirements. This classification or one similar to is should be adopted for use by future space exploration programs, specifically NASA's Constellation Program.

2. The integrated relational database structure described in Section VI allows one to organize the classes of supply dynamically, depending on use cases (logistics planner, astronaut, mission control). This is essential to avoid misalignment of classification schemes between different organizations in the interplanetary supply chain. Using the ISCM integrated database, a multitude of users ranging from astronauts to engineers to personnel in the mission control center can easily run queries on the information of interest to them.

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