

(NASA-CR-197566) INTERNATIONAL
SPACE STATION ALPHA (ISSA)
INTEGRATED TRAFFIC MODEL
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INTERNATIONAL SPACE STATION ALPHA (ISSA) INTEGRATED TRAFFIC MODEL

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Abstract

The paper discusses the development process of the International Space Station Alpha (ISSA) Integrated Traffic Model which is a subsystem analyses tool utilized in the ISSA design analysis cycles. Fast-track prototyping of the detailed relationships between daily crew and station consumables, propellant needs, maintenance requirements and crew rotation via spread sheets provide adequate benchmarks to assess cargo vehicle design and performance characteristics.

Nomenclature

APCU	Auxiliary Power Control Unit
ATV	Automated Transfer Vehicle
CAP	Capability
CV	Cargo Vehicle
COTS	Commercial off-the-shelf software
ECLSS	Environmental Control and Life Support System
ESA	European Space Agency
EXT_AL	Weight of external airlock
FSE	Flight Support Equipment
JSC	Johnson Space Center
H ₂ O	Water
IPT	Integrated Product Team
ISSA	International Space Station Alpha
kg	Kilogram
Max	Maximum
micro-g	Micro Gravity
MPLM	Mini Pressurized Logistics Carrier
nmi	nautical miles
OIU	Orbiter Interface Unit
ORU	Orbital Replacement Unit

PRLAs

Prop
ROEU

RSA
TIM

SRCK_LD

STS_BASE

STS_RES

STWRCK
SUM
ULC

ULC_ATT

USOS

Payload Retention Latch Assembly

Propellant

Remotely Operated Electrical Umbilical

Russian Space Agency Technical Interchange Meeting

Stowage Rack Load Factor

Upmass capability of Shuttle at 230 nmi rendezvous altitude

Space Station Program Office estimated management reserve for post assembly phase

Stowage Rack

Summation

Unpressurized Logistic Carriers

Weight of ORU interface attachment hardware

United States On-orbit Segment

I. Background

The approach discussed in this paper presents the development process and resultant relationships employed in the ISSA Integrated Traffic Model*.

The Traffic Model identifies all vehicles docking to and departing from the ISSA. It characterizes traffic density patterns, upmass requirements for the ISSA, capabilities of cargo vehicles (CV) delivering those requirements, and propellant usage.

The initial development of the Traffic Model capitalized on the Integrated Product Team (IPT) processes put in place at the Johnson Space Center. Continual

enhancements to the Traffic Model is streamlined by the very same processes.

This paper will first discuss the development process followed by a detailed discussion of the key relationships that are required to work together to allow a traffic model to be successfully constructed.

The traffic model considers: the Russian Space Agency (RSA) provided Progress-M, Progress-M2 † and Soyuz-TM; the European Space Agency (ESA) provided Automated Transfer Vehicle (ATV) ‡; and, the Space Shuttle as Cargo Vehicle candidates *.

Input data used by the ISSA Traffic Model is still under development. Results shown in this paper should be considered preliminary and subject to change.

The initial tooling of the ISSA

planning base for the traffic model by defining their requirements in areas such as logistics, Flight Crew System resupply, and Environmental Control and Life Support System (ECLSS) resupply. Other items which include altitude and propellant strategies provide necessary inputs to the traffic model.

The altitude and propellant requirements like the logistics and maintenance requirements are derived from ISSA subsystem and analysis tools that take into consideration all required technical aspects of the ISSA design. The data these tools provide are the key drivers to the Traffic Model. The altitude and propellant numbers become highly interactive with the maturity of the model development, as vehicle launch dates change so do the rendezvous altitudes and ISSA propellant requirements. The analytical processes and tools used to derive these data are not discussed in this paper.

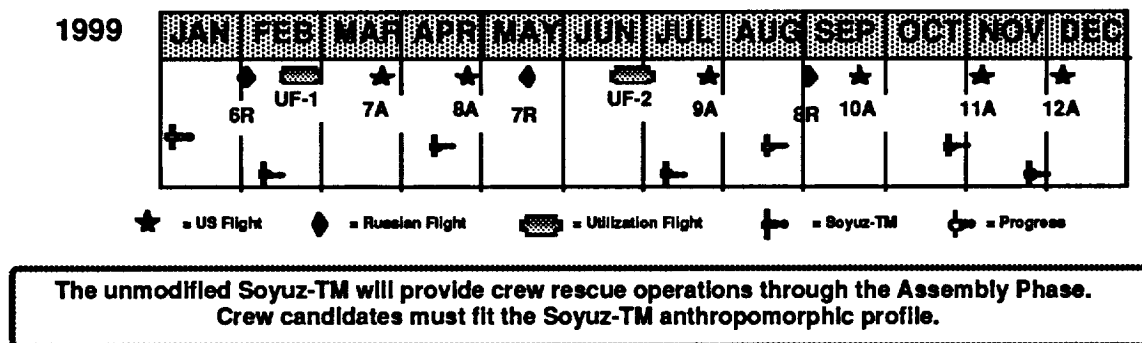


Figure I. 1999 Assembly Year Traffic Density for ISSA

Traffic Model was done on Micro Soft Excel in the Macintosh format *.

II. Traffic Model Development

Each IPT, as part of their on-going design work, established the

Figure I shows the assembly phase traffic patterns / density profile for the year 1999#. As can be seen by Figure I traffic to the station is evenly spread throughout the year. February shows the most amount of traffic with a Russian assembly flight

(6R), a US Utilization Flight (UF-1) delivering the first set of science experiments, and a Russian Soyuz flight rotating up to three (3) station crew members^{††}.

RSA data used in the ISSA Traffic Model is derived from Russian technical reports and information documented in protocols from US and RSA Technical Interchange Meetings[†].

A primary object of the ISSA Traffic model is to project total station consumable rates. This is required in order to identify loading effects on cargo vehicles and to set up the initial architecture of the model. Loading of any cargo vehicle (CV) is determined by examining the duration of stay on orbit and when the next CV is scheduled to arrive. Consumables are identified as propellant, gases, water, and crew supplies ¶.

Another primary objective of the traffic model was the ability to maintain a status of cargo vehicle propellant loading over time. A CV's ability to meet ISSA propellant requirements are paramount to the success of the ISSA. In that light the ISSA Traffic Model must maintain a profile of on-board propellant storage of not only the CV but also the ISSA storage tanks plus keeping track of propellant requirements status. This requires keeping track of the total on-board propellant load while continually comparing it to the contingency propellant storage requirements for the ISSA.

The science requirement for micro gravity constitutes the third objective of the traffic model.

The ISSA must be flown such that once fully assembled some

selected areas on-board must meet a .2 micro gravity perpendicular component to orbital average quasi-static acceleration vector. This environment must be not be disturbed for at least 180 days per year in no less than 30 day increments. The micro-gravity requirement profiles the docking windows for all vehicles going to and returning from ISSA, opportunities for reboosting the station to maintain its operational orbit, and maintenance periods that would impact the station's micro gravity environment.

A micro gravity mission profile was identified for planning guidelines which allows for eight (8) 30 day micro-g periods per year, refer to Figure II, Concept of Operations and Utilization increment definition profile ¶.

II. RSA Key Traffic Model Relationships

Since the ISSA crew members will be using the cargo vehicle as a storage location for the supplies they carry, the loading of water, gases, propellant and crew supplies must be based on how long the vehicle will be attached to the station.

The traffic model considers the use rate of each of the consumables, while the vehicle is attached to the station, in determining the correct CV load factors.

To establish the relationships between the consumables and the loading factors of CVs simple equations have been developed. For these relationships "if/then" expressions are used.

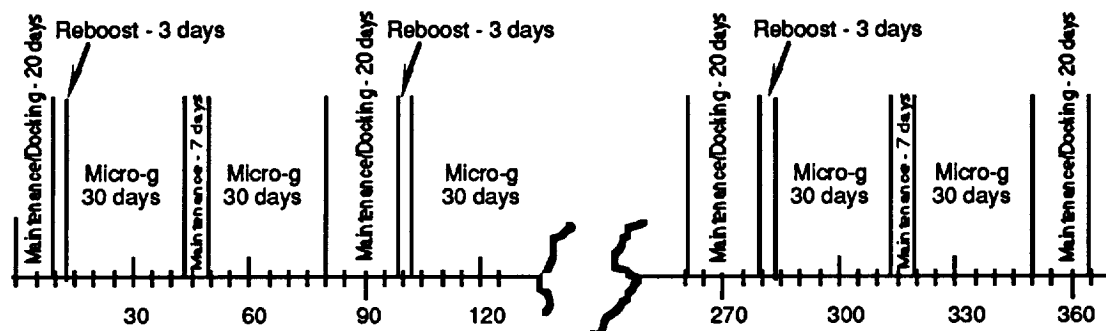


Figure II. Concept of Operations and Principles Micro gravity profile

An "if/then" statement is defined as a calculation or expression that is dependent on a binary condition or conditions. The storage of water considers:

IF(SUM(H₂O) > CV Capability, CV CAP,
SUM (H₂O))

Where as: if the sum of the water required during the stay time of the cargo vehicle is greater than the CVs water tanks then the amount of water assigned to that CV is full water tanks. If not, then the amount of water the CV is to carry is the amount required.

The SUM(H₂O) is determined by calculating the consumable rate of water from the date that cargo vehicle docked to the date the next cargo vehicle docks. This expression not only allows a comparison of requirements and cargo vehicle capabilities, but also the ability to assess different cargo vehicles and changes in capacity designs. This same relationship applies to the CVs ability to carry gases (Nitrogen, Oxygen or a combination of both).

In modeling the operational phase of the ISSA the Traffic Model

assigns the highest priority to crew supplies, then water and gases, followed by maintenance logistics. Any remaining upmass capability is assigned to transport propellant and then to the Experiments. The optimization of CV loading is currently adjusted manually, but this task is a candidate for automation on future ISSA Traffic Model upgrades.

Propellant loading for the CV is determined by the following expression:

IF (CV Max Cap - (CV Base + (230-docking altitude) * CV Orbit penalties) - SUM (CV Load) > = CV Prop Cap), CV Prop Cap, CV Max Cap - (CV Base + (230-docking altitude) * CV Orbit penalties) - SUM (CV Load))

This expression considers the CV type as a variable, the payload capability of the CV, what has already been loaded, the maximum capacity for propellant, and upmass penalties associated with docking altitudes.

Since the basic load of the CV is calculated from consumption rates and duration on-orbit the massaging of docking and departure dates

preserve the necessary loading relationships.

One of the key factors in CV propellant loading is the relationship between propellant available on orbit in both the CV and the station elements to the propellant required during the period the CV will be at the station.

This relationship is continually maintained by first keeping track of the propellant within the Service Module, Storage Tank Module (FGB Module), and the attached cargo vehicle. Then comparing it to on-board propellant requirements at specified events (vehicle docking / departures, reboosts, etc.). The traffic model alerts the user when any event results in a negative propellant margin.

Another aspect of the ISSA Traffic Model is the volumetric loading assessment. An average of 200 kg / Cubic Meter is used for all RSA pressurized cargo ^{*},[†],[‡]. When this loading results in exceeding the capability of the CV an indicator alerts the user of the violation.

For the Space Shuttle rack loading coefficients are used that identify total rack weight, carrying load and volume capability.

III. Space Shuttle Key Relationships

The ISSA Traffic Model investigates two (2) types of Space Shuttle mission scenarios.

The first scenario is a dedicated pressurized cargo mission where a 16 rack, 20,000 lbs (9072 kg's) capacity mini pressurized logistics carrier (MPLM) is used. The MPLM is transported to the ISSA in the Space Shuttle payload bay, upon arriving it

is removed and attached to a common berthing mechanism where it will remain as the crew removes and replaces cargo.

Scenario number two is a dedicated unpressurized Space Shuttle mission where up to approximately 26,000 lbs (11,794 kg's) of unpressurized cargo is transported on two (2) Unpressurized Logistic Carriers (ULC) to and from the space station. The ULC is structure that can allow multiple and various sized unpressurized elements to be delivered and returned in the payload bay of the Space Shuttle.

Space Shuttle Scenario #1 - Pressurized Cargo Flight:

In the first scenario the traffic model algorithms calculate the capability of the MPLM to carry cargo to the station by the following expression:

$$(STS_BASE + (230 \text{ nmi} - \text{docking altitude}) * 100 \text{ lbs}) - STS_RES - EXT_AL - MPLM_ATT - APCU - ROEU - MPLM - 20 * \text{locker_wt} - OIU - 2 \text{ Shuttle crew})$$

Where:

STS_BASE	Upmass capability of Shuttle at 230 nmi rendezvous altitude
STS_RES	Space Station Program Office estimated management reserve for post assembly phase
EXT_AL	Weight of external airlock
MPLM_ATT	Weight of MPLM attachment hardware (PRLAs)
APCU	Weight of APCU
ROEU	Weight of ROEU
MPLM	Weight of MPLM
locker_wt	Weight of 20 middeck lockers
OIU	Weight of OIU

The result of this equation is used as a basis for the cargo loading estimates. After assembly of the space station (post assembly phase) the traffic model assumes 40 % of the available upmass is reserved for science and 60% is reserved for crew supplies and space station maintenance logistics.

The space station design teams are interested in tracking the mass and volume of the maintenance Orbital Replacement Units (ORUs) that can be delivered. Therefore the model takes into consideration the average amount of mass and volume that can be placed in a space station stowage rack and deducts the rack weight from the logistics allocation of upmass. This can be seen in the following calculation:

$$\begin{aligned} & \text{IF (Shuttle upmass capability} > 20000, \\ & \text{IF}((20000 * 0.6 - \text{unpressurized cargo} \\ & \quad - \text{crew supplies}) - ((20000 * 0.6 - \\ & \quad \text{unpressurized cargo} - \text{crew supplies}) \\ & \quad / \text{SRCK_LD}) * \text{STWRCK} \leq \text{logistic} \\ & \quad \text{upmass requirement, (20000 * 0.6} \\ & \quad \text{unpressurized cargo} - \text{crew supplies})} \\ & - ((20000 * 0.6 - \text{unpressurized cargo} - \\ & \quad \text{crew supplies}) / \text{SRCK_LD}) * \text{STWRCK,} \\ & \quad \text{logistic upmass requirement),} \\ & \text{IF}((\text{Shuttle upmass capability} * 0.6 - \\ & \quad \text{unpressurized cargo} - \text{crew supplies}) \\ & \quad - ((\text{Shuttle upmass capability} * 0.6 - \\ & \quad \text{unpressurized cargo} - \text{crew supplies}) \\ & \quad / \text{SRCK_LD}) * \text{STWRCK} \leq \text{logistic} \\ & \quad \text{upmass requirement, (Shuttle upmass} \\ & \quad \text{capability} * 0.6 - \text{unpressurized cargo} \\ & \quad - \text{crew supplies}) - ((\text{Shuttle upmass} \\ & \quad \text{capability} * 0.6 - \text{unpressurized cargo} \\ & \quad - \text{crew supplies}) / \text{SRCK_LD}) * \\ & \quad \text{STWRCK, logistic upmass} \\ & \quad \text{requirement)))} \end{aligned}$$

Where:

SRCK_LD Average load for a
 storage rack

STWRCK Weight of storage rack

The above calculation also takes into consideration the maximum capability of the MPLM and the

upmass capability of the Space Shuttle at the assigned docking altitude.

The spacing of Shuttle launches has been driven by the micro-g profile (Figure II) and the Space Station Freedom retained design features.

These design features include the allocation of 40 % of the upmass to science, the number of stowage and refrigeration racks in the Habitation Module and the capacity of the MPLM all contribute to a 90 day crew supply replenishment cycle. Therefore as a basic scheduling template four (4) pressurized Shuttle mission launches are scheduled on 90 day centers. A 5th Shuttle mission, that carries unpressurized cargo, is scheduled within one (1) of the 90 day cycles.

Space Shuttle Scenario #2 - Unpressurized Cargo Flight:

The unpressurized Shuttle mission scenario is handled in the same manner as the pressurized scenario. Volumetric assessments are handled as secondary checks once the loading of each vehicle is determined. The traffic model calculates the Shuttle upmass capability with the following expression:

$$\begin{aligned} & \text{STS_BASE} + (230 \text{ nmi} - \text{docking} \\ & \quad \text{altitude}) * 100) - \text{STS_RES} - \text{ULC} * 2 - \\ & \quad \text{ULC_ATT} * 2 - \text{PRLA} * 2 - \text{APCU} - \\ & \quad \text{EXT_AL} - 20 * \text{locker_wt} - \text{OIU} \end{aligned}$$

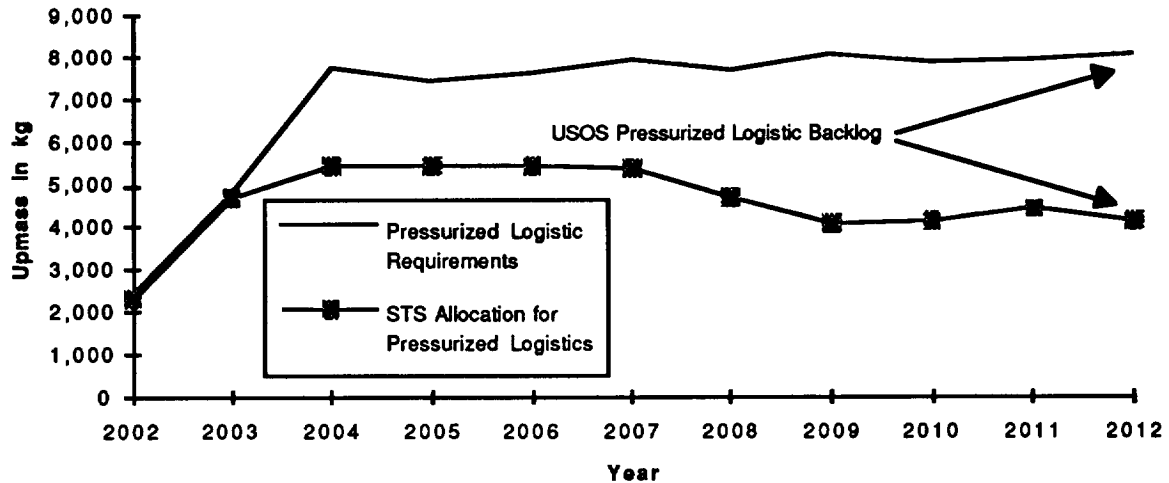
Where:

STS_BASE Upmass capability of
 Shuttle at 230 nmi
 rendezvous attitude

STS_RES Space Station Program
 Office estimated

ULC management reserve
 for post assembly phase
 Base weight of ULC

**MF/MC Resupply Assessment - USOS Pressurized Logist
upmass (based on: 9/28/94 Assembly Sequence)**



**Figure III. USOS Comparison Between Pressurized Logistics
requirements and Resupply Capabilities**

ULC_ATT	Weight of ORU interface attachment hardware
PRLA	Weight of ULC attachment hardware
EXT_AL	Weight of external airlock
APCU	Weight of APCU
locker_wt	Weight of 20 middeck lockers
OIU	Weight of OIU

For the Unpressurized Shuttle flight load capability the traffic model uses the following expression:

$$\text{IF (Science unpressurized upmass + Logistic Maintenance requirements > Shuttle upmass capability, Shuttle upmass capability, Science unpressurized upmass + Logistic Maintenance requirements)}$$

IV. Traffic Model Results

Several outputs of the traffic model are used by the ISSA Program.

The docking and undocking of the visiting vehicles set the basis for determining quiet zones from which micro gravity periods can be planned.

The annual summaries provide comparisons of requirements versus capabilities for both the United States On-orbit Segment (USOS) and the Russian Segment. At the time of this paper the ISSA Traffic Model indicates a backlog of USOS pressurized logistics (refer to Figure III).

The annual average mass of cargo delivered to the station is approximately 100 metric tons per year (includes carrier weights). 20 to 25 metric tons are delivered to the Russian Segment ¹ and is comprised of approximately eight (8) to 11 metric tons of propellant, 6800 kg of crew supplies, 3.3 metric tons of experiment hardware, 2-3 metric tons of water, two (2) metric tons of

maintenance logistics, and 500 kg of gases. The USOS annual average mass is approximately 75 to 80 metric tons and is comprised of 18 to 23 metric tons of science, 8 metric tons of crew supplies, 8 to 12 metric tons of maintenance logistics, and 37 metric tons of Flight Support Equipment (FSE).

V. Summary

All the crew rotation logistics, propellant, and other supply requirements have been aggregates as the basis for defining a traffic model to the ISSA.

Numerous expressions have been developed which allow definition of the various consumption rates and their relationship to each other. This has all been integrated in commercial off the shelf (COTS) software and has set up base rules for enhanced modeling through higher order expressions. Rapid prototyping of certain key design characteristics of cargo vehicles and ISSA capabilities allow for in-depth design assessments in a rapid changing design environment.

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