Abstract

The goal of establishing a long term manned presence on the Moon and eventual exploration of Mars brings the practice of logistics to a whole new level. We describe an approach to logistics as a ‘system of systems’ that integrates logistic system development with vehicle design and mission planning, and provides the basis for a data management architecture that can provide Health Monitoring for the entire logistic system using data from enterprise systems and other resources.

Introduction

We use the term Logistics to describe all of the data, processes, personnel, equipment and facilities necessary to support a system during its intended life. For the program to place a long term manned presence on the Moon, there are basically two stages of the program’s life:

- Support of the actions needed to bring the system into being – acquisition of the system and establishing the lunar based system in place.
- Support of the lunar based system throughout its operational life and ‘retirement.’

The objectives of Logistics for a long term manned presence are the same for systems engineering and design and can be simply stated:

- Protect and sustain life of the crew continuously
- Prevent Mission Critical equipment loss
- Enable primary mission completion.
- Minimize the loss of secondary mission objectives.

These objectives are also the same for both stages of the program. These objectives can be further developed into performance requirements for both system design and Logistic support.

For example, the environmental control system must be capable of continuous operation without failure. This typically leads to a redundant system design which has components capable of providing full system capacity with high reliability and high maintainability.
(or rapid system restoration). These requirements lead to specific, verifiable requirements for mean time to repair, system diagnostics and spares inventories. These requirements are also tied to equipment, technical data and training as enabling elements of repair.

The practice of Logistics has been organized into a series of functional elements that are inter-related and integrated to the maximum possible extent. The elements are enumerated as part of a Integrated Logistic Support (ILS) system in DoD, and many of these same elements have been formulated into support networks for commercial systems such as aircraft. These elements are also connected to the functional elements of systems engineering and design engineering, as design and engineering decisions that affect the system also affect the support of the system, and as support processes are developed they can influence aspects of design. This interrelationship is shown in Error! Reference source not found.

![Figure 1 Relationship of System Engineering and Logistics](image)

These functional elements have a broad span of disciplines, processes and methods and represent a true ‘system of systems.’ For space operations, there are additional functional elements that deserve to be elevated to the top tier of ILS related to habitation and environmental control and long term crew health and well being. In addition, the need for communications within the ILS Computer Resource Support element should probably be elevated to a discrete element as well.
While the objective is to keep these functional elements coordinated and integrated during both acquisition and system deployment, it is extremely difficult to do so. Because of the broad range of disciplines, varying time phasing and duration of actions, different organizational responsibilities (system designer vs. system operator, among others), it is a non-trivial task to keep these activities synchronized and on schedule.

As logistics practice has evolved over the past several decades, more and more information is being shared using computer databases and Enterprise Resource Planning systems in an effort to keep the ILS system synchronized. While these actions have helped, there is still significant room for improvement.

A Systems Based Approach

The Logistics System described in Error! Reference source not found. can be easily seen to be a ‘system of systems.’ Like any complex system, the Logistics components shown have a set of necessary inputs, internal processes and desired outputs. These components (which can be further defined by subcomponents, etc. to whatever level of detail is needed) can be compared to electro-mechanical or electronic components in complex physical systems. Physical components have known failure modes and characteristic behaviors while failing. Similarly, Logistics components can be analyzed for failure modes and characteristics of failure or degradation. Just as we can analyze physical failure modes for ways to sense and measure failure progression (e.g., temperature, pressure, vibration), we believe that logistics component failure modes can be analyzed and their ‘signals’ can be defined, in most cases, from within the data of Enterprise Systems. In addition, with some adaptation from similar efforts, we believe it is possible to establish the characteristics or features in that signal data to identify the presence of component faults or degradation.

We believe that it is possible to develop the means to identify the signals from logistics data systems, collect those signals and process the signals to detect Logistic component degradation while there is time to assess options and make effective corrections. Figure 2 shows a concept for the Logistics HMS. The outputs of the logistic elements are grouped into four major categories (data, personnel, equipment and material) corresponding to the logistic system resources so that decisions regarding resources, processes and finally design can be supported in a cascading sequence of ‘easy’ to ‘hard.’

Systems Engineering tools and process are used in Logistics HMS design to:

- Identify Requirements and establish the means to verify performance
- Contribute to reliability and maintainability analysis and design to support the Logistics System
- Coordinate the trade studies that iterate between system design and Logistic System design
In addition, when analyzing the Logistic System as a ‘system of systems’ for the creation of a Logistics Health Management System, systems engineering methods and tools are used to:

- Formulate the failure modes of system components
- Analyze failure modes for most effective ‘signals’ and sensors
- Establish component failure models and feature libraries

**Figure 2 Health Management System for Logistics**

**Implementation**

Enterprise data systems are growing in scope and capability. Also known as Enterprise Resource Planning (ERP) Systems, these data systems were developed to integrate all functional areas of a commercial entity providing products and services to customers. The ERP community has successfully adapted that basic model to many different enterprises, and Logistics is an area that has received attention in the past decade. These systems collect and analyze transactions which represent the flow of information,
material and finance across organizational boundaries to produce specific outcomes. As such, they generate thousands of new transactions everyday. Attempts to analyze the flow of transactions to predict system performance in the future has remained an elusive goal for ERP because they are primarily designed to assess impact the impact of these transactions on just schedule and cost. Skilled decision makers using the system can generally assess and estimate the impact of growing process ‘bottlenecks,’ but there is little capability for prediction of system conditions in the mid to long term based on the system as it is performing in the near term.

Decisions that affect Logistic components with relatively long ‘time constants’ such as training and equipment design are difficult to connect to increasing Mean Time To Repair after the system has deployed, for example. However, those inter-relationships are real, and should be accounted for during the operational life cycle of the system. We believe that developing an HMS that can either be attached to current ERP architectures, or developing an integrated HMS module for an enterprise system is possible and necessary for effective Logistic System execution. A very basic schematic for such a system is shown in Figure 3.

![Figure 3 A Simplified Architecture for Logistics HMS](image-url)
Summary

The challenges of establishing and supporting long term manned presence in lunar or planetary environs will push the practice of logistics into a much more complex and failure intolerant arena. Conventional logistic support must be supplemented with processes and capabilities to sustain life and long term well being of the crew, as well as supporting equipment with higher requirements for reliability and maintainability.

We believe these factors require significant re-thinking of Logistics as a system of systems and also the way that Logistics is evaluated and managed in both the development and operational phases of the long term missions envisioned. We believe that creating a Health Management System for Logistics that monitors system performance for evidence of fault or degradation, with significant potential to achieve predictive tools is a more effective method than the current ‘enterprise’ method that reacts to process constraints and schedule changes without adequate predictive tools to assess future conditions.