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Paper Session III-B - Space Exploration Initiative Logistics Support - Lessons from the DoD

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SPACE EXPLORATION INITIATIVE (SEI) LOGISTICS SUPPORT LESSONS FROM THE DoD

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Abstract

A mission as complex as the Space Exploration Initiative (SEI) cannot succeed without adhering to sound principles in the planning, development, and execution of logistics support for the exploration crews and their mission equipment. While much attention will focus upon the development of reliable, robust, heavy lift launch vehicles, and scientific, technological breakthroughs for SEI, of equal concern is the supportability and sustainability of systems designed for mission operations and crew life support on the lunar and Martian surfaces.

This nation's military services have developed, operated, maintained, and sustained weapons, supporting systems, and their crews in remote and often in hazardous environments. This paper draws from input made by the Department of Defense (DoD) to the SEI Synthesis Group; Strategic Defense Initiative Office (SDIO) developed logistics initiatives, innovative tools and methodologies; and logistics planning support provided to National Aeronautics and Space Administration/Johnson Space Center (NASA/JSC's) Planet Surface System Office to describe proven and innovative logistics management approaches and techniques used for developing and supporting DoD and SDIO systems. The approach is tailored for lunar/Martian surface operations, and provides a roadmap for the development and management of a crucial element of the SEI logistics support program.

I. Background

The Need for Early SEI Logistics Planning and Analysis

The fundamental requirement for including logistics planning and analysis in developing systems to take man to other planets in our solar system, and to sustain him while safely exploring other planets, has been recognized by the DoD since the early 1960's. At that time the Office of the Quartermaster General of the United States Army proposed to NASA the development of "Supply Support System" for Man in Space Operations. Concepts for this system were to be developed for early one- and two-man short-term missions, and expanded for follow-on missions leading to large-scale, multi-man operations including earth orbiting stations, lunar and Mars bases.[18] Dr. Pat R. Odom's paper, "Space Logistics Challenges in the Early 21st Century," presented at the 23rd International Logistics Symposium, points out that "both lunar and Mars explorations will require new logistics analysis and thinking with regard to the life support of man in the extraterrestrial environments." The logistician must, and will play a key role in developing techniques for making lunar and Martian bases relatively self-sufficient following a build-up period.[15]

Dr. Odom, citing the lessons learned from several DoD programs, concludes his paper with the observation that a comprehensive study of logistics

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problems and requirements involved in major exploration programs rarely begin soon enough. Early study efforts to identify long-lead development areas are always inexpensive when compared to overall cost of development and potential life cycle costs. Current and future efforts to define manned lunar or Mars missions, and their systems, should include participation of senior logistics analysts and planners who can provide the needed perspective for the development and operation of supportable systems.[15]

Other studies and analysis of proposed manned exploration of space have supported the need for early logistics participation. The AIAA Planetary Surface Systems and Technology Working Group reported that one recognized challenge to establishing, operating, and maintaining a planetary outpost is the need to develop an integrated logistics support system that is responsive to the constraints imposed by the unique features of the SEI (i.e., long mission durations, stringent equipment reliability, limited resupply opportunities). The AIAA report goes on to state that "even though the definition of surface architectures and systems are immature (at this time) it will be especially important to integrate and optimize supportability, maintainability, reliability, and availability features of the SEI."[3]

NASA Associate Deputy Administrator, Mr. Samuel W. Keller, in a June 9, 1991 interview, stated that "an overall mission concern (for SEI) is parts reliability. Past moon landing missions required effective parts performance for only two weeks, whereas a Mars mission would last about two years. ...Hardware and systems designs aboard the spacecraft would, therefore, emphasize reliability." This same concern and emphasis will also be applicable to the life support systems, facilities, and mission equipment delivered to and operated on the lunar and Martian surface. Mr. Keller goes on to say that due to the great distance from Mars to the earth, and resulting extended delays in communication, crew members must be able to handle rapidly and independently solve any problems that arise. On-board diagnostic systems will replace technician and engineering consultants on earth in assisting the crews to diagnose and fault isolate equipment and/or software problems throughout the mission. "The on-board system must include engineering drawings, fault tolerance trees, and step-by-step problem resolution instructions." Mr. Keller concludes that "with the need to carry on-board this wealth of technical data, compact information storage will be essential."[14] The technologies being developed by DoD under the Computer-Aided Acquisition and Logistics Support (CALS) initiative are directly applicable to this critical need.

In describing the challenges inherent in establishing an outpost on the planet Mars, Mr. Barney Roberts, Manager of the Planet Surface Systems Office at NASA's Johnson Space Flight Center, wrote "The degree of surface operations (on Mars) will range from the set-up of automated atmospheric stations to assembly, test, and verification of the habitation structures (for housing, crew, supplies, and life support systems). The multitude of outpost tasks span three operational categories: Construction operations, mission operations, and support (i.e., logistics) operations." He goes on to reaffirm the need for affecting system design early as a goal in planning the logistics support for the Mars mission. "This planning must encompass not only the resupply chain to sustain the crew, but also the maintenance strategies for the surface hardware (and software). Mr. Roberts stresses the fact that operations and logistics support of distant outposts on the moon and Mars, are "major drivers in system designs, identification of new technologies, and applications of advanced development projects." He concludes that "incorporating logistics in the conceptual phase allows the system designer to manipulate (influence) the design based on the cost impacts of maintaining the system."[19] DoD's Integrated Product Development Concept is the best example of how supportability factors can be introduced and considered at the earliest phases of system development.

The studies and reports cited above, coupled with several other studies and analysis performed by NASA, contractors, and professional associations, have clearly established the critical requirement for early logistics participation in any manned space venture. Logistics and supportability planning and analysis performed as an integral activity within the system engineering process for the development of hardware and systems for the planetary exploration mission are essential to ensure the mission and crew are supported and sustained. The following section discusses DoD's current involvement in the SEI program and recommendations made by DoD to the SEI synthesis group, focusing upon those issues that are directly and indirectly relevant to the logistics support of the mission; it also reviews suggestions more relevant to roles for DoD in the SEI that will draw from the department's experiences and strengths in developing, fielding, supporting and sustaining major, complex systems and their crews.

II. DoD Participation

Participation by the Department of Defense (DoD) in the planning and analysis for implementing President Bush's SEI program has been accomplished, to date, in three phases: Phase I was DoD's review of NASA's 90-Day Study; Phase II was the DoD input to the SEI Synthesis Group at the request of the National Space Council (NSC); and Phase III was DoD's review of the Synthesis Group's SEI Report. Figure 1 shows the chronology of DoD's involvement in SEI, highlighting the key points of President Bush's 21 February 1990 decision to initiate the SEI.

Phase I - Review of NASA 90-Day Study

At the request of the NSC, all council members (which includes the Department of Defense) were requested to provide an independent review and assessment of NASA's 90-Day Study. The DoD review resulted in the recommendation, among several, that "maintainability planning should be the major pacing element in the system design." Further, it was recommended that the SEI should be "analyzed as a logistic oriented venture as well as a technical challenge." Toward that objective, it was recommended that "operations and maintenance goals be set for the program from the onset." In evaluating the operations concept as it relates to the transportation infrastructure, the DoD recommended that "the launch mission and the supporting systems need to be reviewed and guided through an extensive Logistics Support Analysis (LSA)."[12] Again, application of some form of the proven LSA process to those systems designed to operate on the moon or Martian surface is essential to ensure supportability of those critical systems.

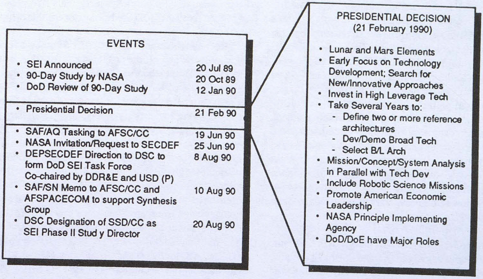

Figure 1. DoD Participation in SEI[12]

DoD's input cited the service's extensive experience in launching and operating space systems; logistically supporting these systems as well as systems operating in extremely harsh or isolated environments; and in developing, constructing, and operating numerous facilities housing military operations. This experience together with the incorporation of many proven features of the DoD acquisition management process can greatly benefit and enhance the SEI. Conversely, opportunities afforded to the DoD by participation in the SEI can contribute significantly to the goal of the National Space Policy "to expand human presence and activity beyond Earth orbit into the solar system," and to "assure access to space sufficient to achieve all U.S. space goals--a key element of national space policy."[22]

Several opportunities were identified for the application of DoD systems for the mutual benefit of the SEI and DoD. Specifically, the recommendation to perform a detailed evaluation of the following DoD programs for application to the SEI was put forth: Global Positioning Systems (GPS), Defense Meteorological Satellite Program (DMSP), Satellite Support Network (SSN), Satellite Control Network (SCN), Military Satellite Communication (MILSATCOM), and small satellites. In addition, several advantages of DoD-SEI cooperation were described including: Shared development and lower operating costs; shared technology; larger manufacturing/manpower base; increased flexibility, operability and robustness (of space launch capabilities); and increased space expertise (i.e., space operational proficiency and capability). Further, opportunities exist to factor SEI requirements into other space programs currently being addressed by the DoD (space infrastructure modernization; advanced and future upper stage development; and several innovative technologies and concepts).[1]

Colonel Gary Payton, formerly the Associate Deputy for Technology at SDIO, and Payload Specialist on Shuttle Mission STS-51C, succinctly summarized the benefits of DoD participation in noting that "with a space budget larger than NASA's, world-wide assets actively engaged in space operations, and a wealth of facilities and expertise in space research, the military should be a major participant in the SEI." He cites the Gemini program as a successful example of a partnership born between the military and NASA in the 1960's. Both agencies benefited from the partnership--NASA benefited from readily available launch vehicles, rendezvous targets and recovery support; DoD gained design, development, and operational experience---neither agency could have executed the program successfully alone." He concludes that "a return to such participation would greatly improve the prospects for SEI, maintain a robust military technology base; improve the military space infrastructure, and retain talented individuals in these times of declining Defense Department budgets and manpower."[16]

Phase II - Input to SEI Synthesis Group

In the fall 1990, an SEI Synthesis Group, headed by Thomas P. Stafford, Lieutenant General USAF (Retired), was directed by the NSC and generally chartered through the Outreach Program to insure that all reasonable conceptual space exploration alternatives have been evaluated. The DoD provided technical manpower to support the group and were also requested as an agency to provide input to the group by drawing from DoD's experience in space to recommend new ideas and innovative approaches to implement the President's SEI.[23] Lieutenant General Donald Cromer, Commander of Air Force's Space Systems Division was appointed to be the DoD Study Director for this effort.

Recommendations to the SEI Synthesis Group by the DoD task force established for this effort reiterated relevant recommendations made earlier during DoD's review of NASA's 90-Day Study. DoD's input emphasized that its extensive experience in space launch and operations; logistics support planning, analysis/ and operations; and design, development of surface facilities and related operations would greatly benefit the SEI. Further, DoD technologies in propulsion, robotics, information processing, and power generation have major, direct application to the SEI (Figure 2). It also noted that many features of the DoD acquisition management system could enhance the SEI program, and recommended that a national program organization be established with active DoD participation.[9] Management, logistics, and systems integration will be critical for the technical success of SEI. The management of SEI must employ the best system engineering and project management techniques available. DoD uses project management, incorporates logistics planning and analysis, and performs integration on small, simple programs to the most complex weapons system. Many of its techniques can be applied to the SEI.

Specific recommendations directed at the logistics and supportability aspects of the SEI program included

Technology Thrust	Technology Program Area	Lunar Outpost Robotic	Lunar Outpost Human	Mars Exploration Robotic	Mars Exploration Human	DoD Technologies Systems
EARTH-TO-ORBIT	Propulsion, Avionics, Manufacturing		●	⊖	●	X
SPACE TRANSPORTATION	Aerobraking		●	●	●	X
	Space-Based Engines		●	⊖	●	X
	Autonomous Landing		◒	◒	◒	
	Auto. Rendezvous and Docking		◒	◒	◒	X
	Vehicle Structures and Cryo Tankage		⊖	⊖	◒	X
	Artificial Gravity				●	
IN-SPACE OPERATIONS	Cryogenic Fluid Systems		◒		◒	X
	In-Space Assembly and Construction		◒		◒	X
	Vehicle Servicing and Processing		◒		◒	X
SURFACE OPERATIONS	Space Nuclear Power	◒	●	◒	●	X
	In Situ Resource Processing		●	⊖	●	X
	Planetary Rover	◒	◒	◒	◒	X
	Surface Solar Power	⊖	◒	⊖	◒	X
	Surface Habitats and Construction		◒		◒	X
HUMAN SUPPORT	Regenerative Life Support		●		●	X
	Radiation Protection		●		●	X
	Extravehicular Activity Systems		◒		◒	
	Exploration Human Factors		⊖		⊖	X
LUNAR AND MARS SCIENCE	Sample Acq. Analysis and Preserv.	◒	⊖	◒	⊖	
	Probes and Penetrators			◒	⊖	
	Astrophysical Observatories		◒			X
INFORMATION SYSTEMS AND AUTOMATION	High-Rate Communications	⊖	⊖	◒	◒	X
	Exploration Automation and Robotics	◒	◒	◒	◒	X
	Planetary Photonics	⊖	⊖	◒	⊖	X
	Exploration Data Systems	⊖	⊖	◒	◒	X
NUCLEAR PROPULSION	Nuclear Thermal Propulsion				●	X
	Nuclear Electric Propulsion				●	X

Legend: ⊖ *High-Leverage Technology* ◒ *Enabling for Some Exploration System Options* ● *Critical Exploration Initiative Tech.*

Figure 2. Application of DoD Technologies/Systems[9]

the need for operations and maintenance goals to be set at the onset of the program. Additionally, the need for developing more streamlined acquisition strategies and procedures (an initiative currently receiving emphasis within DoD) was also repeated. In the area of SEI operations and support (O&S) the DoD input stressed that low maintenance, high reliability and availability systems must be designed. Redundant systems must be avoided or at least limited to highly critical components. Further, DoD stressed that proper O&S analysis can provide the methodology required to answer these issues. The methodologies referred to include the proven technique of Logistics Support Analysis as defined in MIL-STD 1388-1A and development of models, tailored for the requirements of SEI to evaluate alternative O&S concepts considered for the SEI missions, similar to the modeling and simulation initiatives put forth by SDIO and implemented at the National Test Facility (NTF), Falcon Air Force Base, Colorado.[9]

Lt. General Cromer has suggested that the NTF's integrated network of computer and hardware-in-the-loop simulations could let the government perform independent Test and Validation of various exploration options. He stated that "doing trade-offs on a moon-Mars testbed could improve government and contractor understanding of hardware performance requirements. A test bed's real-time simulations of Command, Control, and Communications (C^3) systems could also provide insight into computing demands for manned and unmanned bases. Further, DoD's experience with satellite navigation and remote base operations could also provide useful information for construction and operations of lunar and Martian installations."[11]

The benefits of utilizing high fidelity simulations in the planning and analysis for the SEI as suggested by General Cromer was supported in a paper by Barney Roberts of NASA/JSC. He states that the demanding requirements for a Mars outpost dictate the use of high fidelity simulations throughout the development phase of the program. Access to such simulation capability, in the long run, will accelerate understanding of key technologies and human factors issues, ensure compliance with system requirements and specifications, and reduces development costs.[19]

Although mostly related to wartime theater of operations, the DoD has extensive experience in developing O&S models for analyzing equipment and systems designs for low maintenance, high availability and reliability. The DoD has recommended that selected models could be tailored or modified to the requirements of the SEI. These models could be extremely useful in helping to determine the acquisition and deployment sequence of alternative reference missions; assist in the engineering design and development, trade-off studies, testing and evaluations necessary to minimize the number of redundant systems or even unnecessary systems considered for the SEI architecture; and contribute to the estimates of mission life-cycle costs.[9]

Phase III - Quick Review of Synthesis Group Report

Many of DoD's recommendations were incorporated into the Synthesis Group's report on the SEI. Of significant interest to DoD's logisticians was the group's recommendation that DoD become a key participant with NASA, DoE, DoT, and other government agencies in a National Program Office to be established by Executive Order. DoD would be an active participant in establishing with NASA a long-range strategic plan for the nation's civil space program, with SEI as its centerpiece. Key elements of this plan would address operations, infrastructure, and logistics support of future civil space programs, including SEI. In response to DoD's recommendations on the need for acquisition streamlining (for SEI), the report also suggests that a new, aggressive acquisition strategy be adopted for SEI to override all agencies' red tape and to more effectively utilize the Federal Acquisition Regulations (FARs). Additional recommendations made by DoD in incorporating SEI heavy lift requirements into a joint NASA-DoD program were also included, along with several joint technology development opportunities.[10]

In summary, the DoD views its role in SEI to include: Maintaining its industrial base for the future; maintaining assured access to space; leveraging spin-off technologies (for DoD application) and enabling needed systems development; and lastly, taking the lead for space transportation, space control, and logistics support utilizing the experience and resources currently in the DoD.[9]

III. Using DoD's Integrated Logistics Support Approach for SEI

Integrated Logistics Support (ILS) as applied to DoD programs is defined as a disciplined, unified, and iterative approach to the management and technical activities necessary to: integrate support considerations into system and equipment design; develop support requirements that are related consistently to readiness objectives, to design, and to each other; acquire the required support; and provide the required support during the operational phase at minimum cost. This definition, contained in DoDD 5000.39, "Acquisition and Management of Integrated Logistics Support for Systems and Equipment,"[2] has recently been expanded and incorporated into the new (February 1991) DoD 5000 acquisition directives for defense acquisitions, superceding DoDD 5000.39 and a myriad of other DoD directives and instructions.[5,6,7] Of the new policy and procedure directives, DoD Instruction 5000.2, "Defense Acquisition Management Policies and Procedures," captures the heart of DoD's historical "lessons learned" from developing, fielding, and sustaining weapons, crews, and systems in support of the U.S. Armed Forces. DoDI 5000.2 establishes the core fundamental policies and procedures for implementing, without supplementation by the individual services, all major elements of the acquisition process, including ILS.[7]

ILS policy initially emphasized the integrated development of a total logistics support structure in lieu of developing individual ILS elements in isolation. This aspect of ILS continues to be extremely important; however, the current emphasis is on introducing logistics and supportability considerations in the "front end" of system development. Early identification of logistics and supportability objectives into specific supportability design specifications is necessary to achieve system logistics and supportability objectives at an affordable life cycle cost.[8] Implementation of current, innovative techniques and methodologies to achieve the logistics and supportability goals and objectives defined in DoDI 5000.2 are best illustrated in the approaches taken by the Strategic Defense Initiative Office (SDIO) to optimize supportability of the Strategic Defense Systems (SDS) under development.

Emphasis on addressing supportability issues early in concept development and later in the research and development process is the driving philosophy behind all SDI programs. Although identification of technological opportunities to enhance logistics support of a system has long been one of several tasks performed under the LSA process, the exploration of technologies to support future logistics capabilities and consistent design approaches has taken on added emphasis for SDI programs. Logistics technologies are being explored in a broad range of areas applicable to future space programs. Examples of enabling logistics technologies with direct application to SEI include telerobotics; contamination control; assembly/ disassembly of large structures; fluid storage and transfer; and orbital replacement unit (ORU) design, storage, and transfer. Additional areas include investigation of the benefits of subsystem/component standardization; concepts for improved hardware and software diagnostics; exploration of maintenance technologies (including on-orbit maintenance and servicing via robotic means, where warranted), and automated approaches to acquire, maintain, and understand the vast quantities of data which would be generated by a future SDI (and SEI) systems. These supporting technologies are considered an integral part of the research and development process within SDIO. Many of the operational technologies being explored by SDIO are at the outer edge of the technical envelope, pushing or beyond the current state of the art. Affordable logistics support for these technologies will itself push the state of the art, and will require both innovative support concepts and new technical support capabilities.[21] Several technologies and innovative approaches to maintenance concept development and planning for SDIO programs were recommended by DoD for direct application to the SEI mission: Of particular interest was on-orbit satellite refueling and maintenance; and development of high fidelity, discrete event simulations for evaluating alternative support concepts.[9]

In addition to providing increased attention and focus on the development of logistics technologies and the use of simulation models to develop and refine support operations, SDIO supportability policies stress the use of Logistics Support Analysis as the principal means through which stated and derived ILS requirements are linked at the system level. Selected areas of particular SDI emphasis offering high payback potential relative to initial cost over the system life cycle were identified for special consideration and integration into system designs during early conceptual stages. Some key areas relevant to SEI include: standardization of system, subsystem, and component level; early development of maintenance concepts to permit general support planning, rough costing, and identification of areas requiring technology development; application of Computer-Aided Design (CAD) integrated with Computer-Aided Manufacturing (CAM) and Computer-Aided Logistics (CAL) to assure system design and support are fully integrated; assessment of logistics technologies; early consideration of technical data information needs and approaches for more effective methods to develop, store, display, and use; and logistics information management, data collection, and analysis techniques to assure system support experience is captured in a manner to permit analysis of system characteristics, attributes, and related costs.[21] These and several additional high payback areas not mentioned here can also offer high payback benefits for the SEI.

IV. Example of DoD Logistics Approach to SEI - A Case Study

To illustrate an approach to developing a logistics support program for maintaining systems designed for mission operations and crew life support on the lunar and Martian surface, a case study drawing from work performed during 1990 by PRC, Inc. for NASA/JSC's Planet Surface Systems Office is described below. It shows how incorporation of DoD's proven and innovative logistics management approach, tools, and techniques can substantially benefit early logistics planning for the SEI, while also implementing many of DoD's recommendations for SEI summarized earlier in this paper.

A feature of the NASA logistics support concept for planet surface systems is a phased approach emphasizing the need to incorporate an "evolutionary decentralized concept." The first phase, Emplacement, would make maximum use of logistics support (to the scientific missions performed on the planet surface) originating from the earth, with allowances for selected crew autonomy to perform operations planning at the outpost; a possible second phase, Consolidation, would use Space Station Freedom or other orbital staging area, as an intermediate mode for providing most levels of maintenance activities in support of surface systems, supplemented with increasing logistics support capabilities at the outpost facilities, while reducing dependance on logistics support originating directly from the earth; the final phase, Exploration Operations, would provide the means for the crews to perform far more significant repairs at the outpost logistics facilities utilizing resources developed/ manufactured from materials indigenous to the lunar or Martian planets. The overall goal was to significantly reduce costly resupply/logistics shipments from the earth while maximizing outpost self-sufficiency.[17] Figure 3 graphically portrays this evolutionary concept. Inherent in the logistics planning for this approach is the development of a supportability data base to capture and refine experience gained from the operations and support of the surface systems throughout the evolutionary process. Data gathered over time would be fed back into designs for follow-on generation of systems for deployment on Mars.

Based upon NASA's preliminary operations concept and the top-level, corresponding support concept described above, goals were established for the development of a logistics support infrastructure capable of sustaining the mission to be performed on a planetary surface. These goals embodied the following features:

- Evolutionary, cost efficient, incremental development
- Support capabilities tailored to the unique requirements of each mission phase
- A transportable, transferable support system capable of modification and growth to meet evolving operational needs
- A common, integrated logistics support data base interfaced with system engineering and design engineering to capture maintenance and support technical requirements, parameters, and data.[13]

To attain these goals, the SEI logistics support program

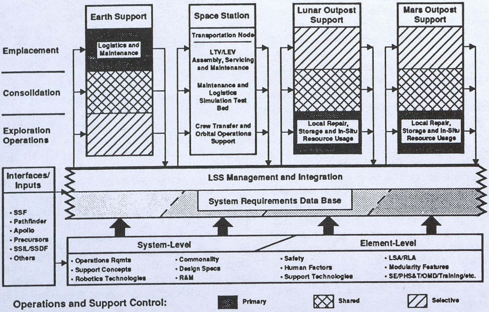

Figure 3. Evolutionary/Incremental Logistics Support System Development[13]

would develop clear, comprehensive logistics management plans to guide the development effort; analytical tools to assist in evaluating a broad range of possible scenarios; and adapt or create methodologies with which to explicitly define supportability-design-to requirements and resource requirements to implement the SEI support plan, and to measure progress toward attaining the goals shown above.

The following support system objectives were also established to guide the development effort:

- Identify and quantify support requirements and considerations
- Develop and refine support concepts and plans consistent with operations
- Optimize commonality in both system and element designs and support operations
- Incorporate modularity features into system designs
- Ensure systems and equipment are designed for ease of maintenance
- Early identification of critical spares, long-lead items, support cost drivers, and failure rates
- Identify robotic performance of hazardous maintenance and operator tasks
- Assess the impact of evolving technologies on the support concept.[13]

Given the tenets now documented in DoDI 5000.2, coupled with the goals and objectives of the logistics support system (LSS) for planetary surface systems, a phased development approach can be established patterned after the traditional acquisition development phases followed by DoD programs. Figure 4 shows how such an approach would be planned reflecting key logistics events occurring throughout the NASA acquisition phases; analysis/activities performed during each phase; and primary logistics output or products of each phase leading to deployment of supportable and supported surface systems during each of the emplacement, consolidation, and exploration operations phases of the SEI mission.

To accomplish such an ambitious program, one must start with an understanding and application of some very fundamental approaches for incorporating ILS as described in DoDI 5000.2. These approaches, adapted for the SEI, could be described in the following manner:

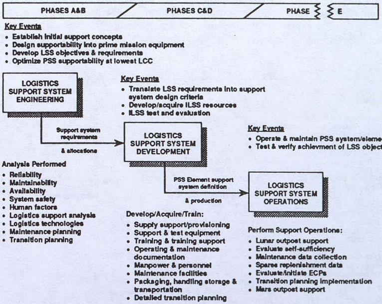

Figure 4. Phased Approach to Surface Systems LSS Development[13]

1. Analyze and influence the surface system and element designs for supportability features (i.e., modularity, standardization, commonality, safety, transportability, reliability, maintainability, etc.)

2. Evaluate the impact of operational requirements and concepts upon support requirements and considerations. For example, consider the impact of:

   - Long-term human presence on planetary outposts
   - Crew performance on the planetary environment
   - Maximizing crew self-sufficiency from earth resupply and support
   - Decentralized control of lunar and Martian operations.

3. Define surface systems logistics support requirements for: habitation and human systems; power production and distribution; science experiments; in-situ resource utilization; and launch and landing operations.

4. Explore innovative support concepts, processes, and technologies. For example, the following sources should be thoroughly explored:

   - Space Station support concepts and technologies applicable to surface habitation and human systems
   - Supporting and enabling technologies from SDI i.e. robotic maintenance, assembly and fuel transfer; simulation of operations (transportation and planet surface); autonomous docking, etc.
   - Application of candidate technologies from DoD's CALS initiatives such as digital imaging for paperless tech data; automated information sharing among developers, subcontractors/vendors, and government; graphic technical instructions; integrated diagnostics; damage assessment aids; computer aided training; etc.
   - Adaptations from other NASA technology programs
   - Independent studies and analysis performed by government agencies and contractors.[13]

The suggested approaches described above are normally products of an LSA program; a recommendation of the DoD for SEI. An indispensible tool for supplementing the logistics analysis process in optimizing the design for supportability, the support concept, and resulting maintenance plans for surface systems is the development and use of a surface systems

Table 1. Surface Systems Simulation Content [13]

Launch Vehicles and Cargo Manifests

Resources at Earth, Space Station Freedom, and Outposts
- System elements
- Personnel
- Consumables
- Spares

Constraints on Resource Availabilities

Equipment and Facility Design Information
- Mass
- Modularity
- Reliability
- Maintainability
- Commonality
- Consumable Usage
- Consumable Production

Planned Operations
- Launches
- Rendezvous with Space Station Freedom plus Related Operations
- Landings
- Unloading Cargo
- Transport of Crew, Equipment, Raw Materials, LLOX, Waste, Construction Materials, Facility Components
- Construction (Grading, Trenching, Hauling, and Piling Regolith)
- Facility/System Assembly
- Scientific Data Gathering
- Surface Mining
- Maintenance and Repair
- Monitoring Systems and Operations
- Planning
- LLOX Production

Unscheduled "Events"
- Hardware Failures (Equipment, Vehicle, Facility)
- Operational Failures
- Excessive Rates of Consumable Usage
- Excessive Operations Times

Planned Responses to Unscheduled Events
- Repair
- Replace
- Resupply
- Crew Workarounds
- Return to Base
- Return to Earth

Life Cycle Cost Information
- Cost breakdown structure
- Cost estimating relationships
- Cost parameters

simulation model. To demonstrate the value added by a simulation model that generates extra-terrestrial logistics support requirements, the SEI mission profile outlined in the NASA 90-Day study was utilized. It should be noted that the model can be applied equally well to any of the subsequently proposed Lunar/Mars architectures. The general content of such a simulation model is shown in Table 1. To be effective, the model must simulate the interactive integration of scheduled servicing and maintenance activities into the operations timelines, and also be capable of providing an interactive assessment of the impact unscheduled maintenance may have on scheduled operations, timelines, and schedules. For example, the model should account for dynamic constraints on support resources caused by environmental conditions, or due to availability/non-availability of support/test equipment, tools, consumables, or crew members for performing scheduled or unscheduled maintenance and servicing tasks.[13] Interaction of a surface system logistics simulation model with a hypothetical LSA program, tailored for "up front" analysis of SEI, is shown in Figure 6. Logistics scenarios under evaluation, logistics and supportability requirements, and applicable supportability factors are obtained from the LSA data or LSA Record (LSAR) for input to the simulation model. Outputs from the model are analyzed and evaluated for contribution to the development and refinement of the

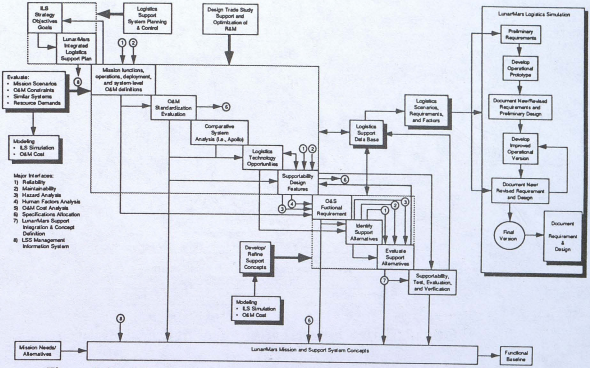

Figure 6. Logistics Support Analysis Interaction with Logistics Simulation Model

preferred support concepts. This approach to support concept development has been used by the Air Force with excellent results on several SDI satellite programs. Deployment scenarios, support concepts, and satellite sparing strategies have been significantly impacted by using this logistics simulation approach recording life cycle cost savings ranging from .5 to 41 billion dollars.[4] Figure 7 shows how use of a simulation model can supplement other analysis in the evolution of the surface systems logistics support concept. This interactive process involving the SEI government team and the SEI hardware contractors will evolve to refine the surface systems support concept. The system-level concept is further defined by the individual surface system element-level (i.e., habitation and lunar systems, launch and landing systems, etc.) support concepts, and will fully encompass the support requirements for earth-based, space station, and surface systems.[13]

Technology developments on prime mission equipment, or logistics technologies that could impact

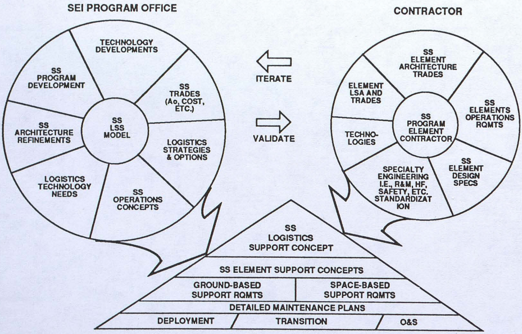

Figure 7. Surface Systems Logistics Support Concept Evolution [13]

support concepts, are factored into the analysis; refinements/changes to operations concepts and plans must also be considered. Government developed support concepts using this approach can be iterated with the concepts developed by the competing element contractors to further validate, refine, and optimize the preferred concept at substantially reduced costs. This iteration and validation of the logistics planning and development process should continue throughout program growth and maturity leading to baseline support concepts at the surface system element-level. As element-level LSA/LSAR development continues, identification and quantification of specific ILS resources will be documented. This process leads to the preparation of detailed maintenance plans and technical data for use by the crews on the lunar and Martian surfaces. These detailed plans will provide the basis for maintenance support of element-level systems as the SEI systems are deployed and transition through the emplacement, consolidation, and exploration operations phases.[13]

V. Conclusion

This nation's military services have developed, operated, maintained, and sustained weapons, supporting systems, and their crews in remote and often hazardous environments as a fundamental element of the military establishment from the early days of our founding fathers to the present age of space. This paper has presented a brief overview of the DoD participation in the SEI program to date, and included observations of the benefits that application of the DoD approach would provide to ILS development for surface systems employed on the lunar and Martian surface. A representative case study, drawn from an effort to instill the DoD approach in NASA's planning and analysis for their planet surface systems, was presented to introduce in a limited way an approach drawn from the authors' combined years of DoD operational and acquisition logistics experiences. It is not intended to be an all-inclusive primer for SEI logistics, as much remains to be learned about the SEI; nor does it represent an official position of the DoD agencies represented by the authors' affiliation. The paper is merely intended to provide a glimpse of the future for military logisticians who have labored long and hard to refine the DoD way of developing and fielding supportable and supported systems for our military services over the past 200 years.

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