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# LOGISTIC SUPPORT ANALYSIS and the STRATEGIC DEFENSE SYSTEM

## MIL-STD-1388-1A Applied to a System of Systems

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## ABSTRACT

This paper presents one approach to applying Logistic Support Analysis (LSA) to the highly complex and logistically unique Strategic Defense System (SDS). The paper briefly addresses each of the LSA primary task areas and the additional analyses required by the statement of work (SOW) tailoring of the LSA. Each specific LSA task is addressed and key sub-task points are noted. Relatively detailed discussions of the analysis process of identifiying supportability functions, alternatives and trades constitute the majority of the paper. In the course of the analyses emphasis was placed upon early identification of logistics factors that could influence SDS design to enhance supportability, reduce life-cycle costs (LCC), optimize system readiness, and eliminate or mitigate logistic problem areas. It should be noted that three primary factors make this LSA effort unique: first, SDS is accurately described as a "System of Systems" which necessitates a top-down approach in the analysis; second, maintenance and servicing of space-based assets, particularly on this scale, have no precedent and require new approaches to achieve cost effectiveness; and third, these types of satellites, with the necessary modularity for servicing, have not been previously constructed. Finally, the adoption, development, and/or use of computer models to identify high-cost drivers, conduct sensitivity analyses and tradeoffs is discussed.


## INTRODUCTION

The Logistic Support Analysis (LSA) effort is an iterative process, beginning at a high, conceptual level and increasing in scope, depth, and detail as a program develops. The LSA for the Strategic Defense System (SDS) is being conducted in accordance with MIL-STD-1388-1A (Logistic Support Analysis). This endeavor would not appear unusual for any other current military system. However, SDS is best described as a "system of systems" (e.g., sensor systems, and both ground- and space-based weapons systems), while 1388-1A was developed for application to a single system (e.g., tank or aircraft). The SDS LSA addresses the supportability of systems in both basing environments, demonstrating the adaptability of MIL-STD-1388-1A, which was written when space-based assets were not considered supportable once placed in orbit. This paper focuses on the tailored logistic support analysis conducted on the space-based systems.

From the earliest planning stages for SDS, it was anticipated that an innovative, well-designed support system would be a critical element in fielding an affordable system. Because of the many design "firsts" and the new technologies involved, a method for incorporating supportability into the design, and for designing an adequate support system, was essential. The most effective known method for accomplishing this was an iterative, and thorough, logistic support analysis process.

## PURPOSE

The purpose of this paper is to describe the ongoing LSA process for the space-based portion of SDS by briefly describing the applicable LSA tasks and subtasks defined in 1388-1A, describing specially tailored analysis tasks, and presenting primary results of the analyses.

* Member AIAA

## SCOPE

The LSA conducted on the SDS to date has focused on Phase I system elements (shown as shadowed boxes in Figure 1), while addressing the complete architecture in more general terms. The analysis has been concentrated at the system level, in order to gain logistic insights and to determine the bases for policies that will improve SDS supportability and affordability while maintaining system readiness. The process was approached from a standpoint of examining selected system elements, with an objective of identifying those qualitative and quantitative design/supportability factors which extend across multiple system elements. These shared factors, therefore, are viewed as system-level issues which may be further analyzed. Space-based interceptor (SBI) and exoatmospheric reentry interceptor system (ERIS) have been the primary system elements examined. Their large sizes and high costs provide the greatest potential for affordability/supportability improvements among the SDS Phase I space-based and ground-based segments, respectively. This paper will primarily discuss LSA conducted on the SBI system and the results of the iterative process over the past 1 1/2 years.

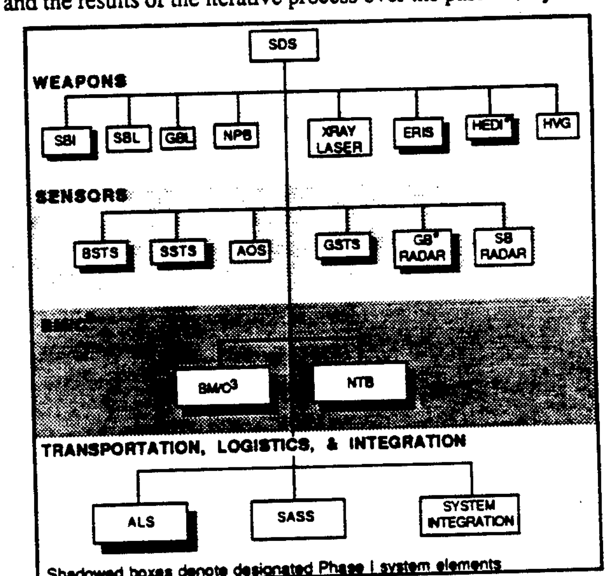


FIGURE 1 - PROPOSED SDS ARCHITECTURE

## DISCUSSION

General. Details of any logistic support analysis vary greatly with the stage of system development. When LSA was initiated on SDS, the system was in Concept Definition phase; during the intervening period, some elements of the SDS have progressed to the early part of the Demonstration/Validation phase. Figure 2 is a flow diagram of the analysis tasks that have been performed, and those being updated consistent with system development for the SDS. Those familiar with LSA will note the absence of 400 series tasks, which cannot be performed effectively in this early development stage nor at the "system-of-systems" level. There were two major challenges in preparing the logistics analysis; first, at the initiation of the LSA process, several architectures

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were under consideration; and second, rapid SDS technology development has outdated some portions of the analysis almost as soon as they were completed.

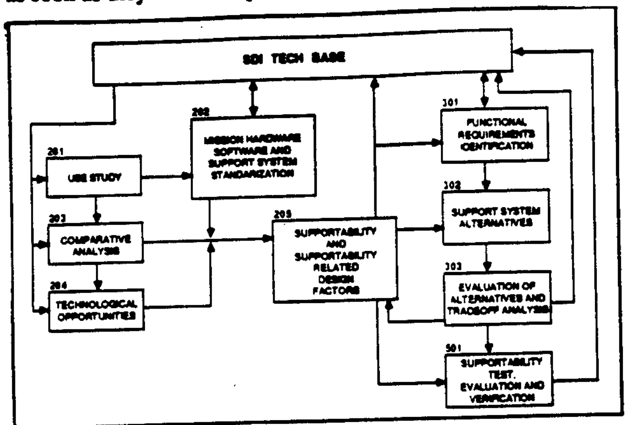


FIGURE 2 - THE LSA PROCESS AS TAILORED FOR SDS

100 Series Tasks Task 101, the LSA Strategy and the initial document prepared establishes the general goals and scope of the system LSA. Task 102, the LSA Plan (LSAP), is a road map for implementing the SDS logistics support analysis strategy and the Strategic Defense Initiative Organization (SDIO) Supportability Research Policy. It is, therefore, a plan for integrating support and logistics considerations with system architectures, concepts, and design activities during development, acquisition, and production of the SDS system elements. It specifically addresses the actions required to satisfy detailed supportability objectives to achieve an affordable and supportable SDS, as stated in the policy and strategy. Task 103 is a report of the LSA In-Process Reviews. The major difference between these and similar documents for any other complex military system is the increase in scope resulting from the multiplicity of systems.

200 Series Tasks The 200 series tasks begin the actual logistics analysis process. Using the foundation of the LSA Strategy and the LSAP, the 200 series tasks develop the framework for the later tasks that, when completed, will establish the support concept. The 200 series tasks and primary subtasks are summarized below.

Task 201. Use Study. This task examines the proposed system architecture(s), describes the system from a logistics standpoint, and proposes a general maintenance concept. Because this analysis deals with specifics of candidate SDS architectures, the report is classified. To prepare the system description with multiple architectures, a matrix approach was selected. During this initial effort, the various architectures included all system elements, e.g., both space-based directed energy weapons (DEW) and kinetic energy weapons (KEW). The matrix depicts the primary system elements by function and the text addresses those requirements/characteristics expected to have significant logistic impact. The maintenance concept also requires individualized approaches for the space-based and ground-based assets. The maintenance concept for ground-based assets emphasizes minimizing manpower requirements. The maintenance concept for space-based assets assumes an evolving form of on-orbit maintenance and servicing in order for large satellite constellations to be affordable and to meet operational readiness goals.

Task 202. Mission Hardware, Software and Support System Standardization. This task identifies early in the LSA process those areas in which common procedures, processes, or subassemblies could be used to enhance supportability and/or affordability. The approach is conceptual, rather than specific, in view of the early stages (and concomitant tentativeness) of system development. Subtasks include support resource identification and examination, supportability impact analysis, and recommended mission hardware and software standardization approaches. In addition, the LSA tailoring process added requirements to:

- Analyze the impact of metrication on the SDS;
- Analyze and compare the architecture(s) vis-a-vis Ada and determine whether Ada should be the standard software language for SDS;
- Identify logistics computer models and recommend models as standards for SDS use.

Highlights of the analysis results include:

- Recommendation that subsystem standardization, inter and intra-system element be based on the concept of form, fit, and function ($F^3$);
- Recommendation that SDS system elements be designed and built using the SI (le Systeme International d'Unites) system of measurements;
- Recommendation that Ada be the standard software language for SDS;
- Production of a logistics model catalogue containing an extensive listing of models that may be used in the conduct of SDS logistics analysis.

An SDIO policy, issued in November 1987, stipulates that the SDS utilize the SI system of measurement. This selection was predicated on the long standing goal of the US to convert to metrics, the inclusion of other standards (e.g., IEEE) within SI, and the absence of significant additional costs for systems which have been designed in metrics as opposed to US customary units. Ada has been adopted as the primary software language since analysis showed it was compatible with supercomputers, artificial intelligence and expert systems, and massive parallel processing. These capabilities allow SDIO a wide latitude in the use of computing hardware and software. The Logistics Model Catalog was distributed within the SDS community beginning in April 1987, has been updated, and is now being disseminated outside of the SDIO community when appropriate requests are received.

Task 203. Comparative Analysis. Because portions of the analysis are classified, this discussion is limited to the general concept and approach. The task involved evaluating currently fielded systems that were functionally suitable and logistically similar to the proposed system so that a logistics comparison baseline could be established.

Another evaluation consideration was data availability. Under ideal circumstances, comprehensive data on the existing system should provide a baseline for spares costs, manpower requirements, training requirements, mean-time-to-repair (MTTR), mean-time-between-failures (MTBF), etc. For the SDS, this effort required notionalizing because, for some systems, no reasonable comparator existed; for others, a comparator was synthesized from components of several different systems. In some cases where a comparator existed, no data was available.

A compilation of currently operational systems that are logistically and functionally similar to the new SDS system elements has been used to synthesize a baseline comparison system (e.g., Aegis is the comparison system for the Battle Management/Command, Control, and Communications system, and Phoenix is baseline for orbiting KEW).

Task 204. Technological Opportunities. This analysis identifies technologies expected to contribute to SDS supportability, thereby reducing life-cycle costs (LCC). The systems within the SDS that are pushing the frontiers of technology for operability and supportability have made this task particularly challenging. Because accomplishment of this task depends heavily on data collection, collation and analysis, those working on SDS have contributed by noting applicable information in professional periodicals and attending related symposiums. National technical databases were scanned for new technologies and an SDS-specific database was established to facilitate data retrieval. Specific subtasks accomplished include:

- Identification, evaluation, and recommendation of

specific design technologies to achieve required supportability levels on the various SDI systems;
- Development of qualitative estimates of potential improvements in support cost and system effectiveness parameters expected from new/specific technologies;
- Identification/assessment of logistics support system improvement options.

Initial results and recommendations include: use of built-in-test (BIT) and integrated electronics; application of advanced computer resources support methods, especially for software support; emphasis on improved cryogenic refrigeration systems; continuing research in the transfer of fluids, including cryogenic fluids, on orbit; and continuing emphasis on design and support technologies, such as computer-aided engineering (CAE), computer-aided design (CAD), computer-aided manufacturing (CAM), computer-integrated manufacturing (CIM) and computer-aided acquisition and logistic support (CALS).

Integrated electronics offers reduced volume, mass, and power requirements and opportunities for improved fault detection, isolation, and recovery. Integrated electronics also support BIT, which is considered essential for an affordable on-orbit support system, and are compatible with the Modular Electronics System Architecture (MESA) concept.

Computer resources support, especially in the software area, will be a major cost driver for the SDS. Initial analysis of this technology area suggests that modular development of software offers the best opportunity to control development and support costs. Automated software development techniques are being reviewed in detail, and software development and support are also the subject of special studies aimed at optimizing software effectiveness while holding down life-cycle cost.

Cryogenic cooling will be required for several SDS systems. Some of these will be ground-based (and relatively easily accessed) while some will be space-based. Most current satellites that require cryogenic cooling have relied on Dewar flasks containing stored cryogenic fluid. Although this technique is satisfactory for relatively limited periods or where only modest additional cooling is required, it is not suitable for IR systems intended to be functional for up to 10 years nor for systems which must acquire cold bodies at long ranges. Another technology essential for space-based support is fluid transfer on-orbit. The major challenges here are those associated with leakproof couplings that are easy to mate and de-mate. This latter criterion is especially important when considering the contamination problems that could result from hydrazine or other fluid spills. Transfer and measurement of cryogenics in zero gravity also require more research to enhance supportability.

Design and support technologies under evaluation are primarily evolutionary but offer significantly reduced costs. For example, the integration of CAD, CAE, and CAM offers significant opportunities to improve producibility and supportability. As CALS matures it is expected to capitalize on the foregoing systems and further enhance supportability.

An LSA Analysis Decision Tree has been used to identify SDS support and logistics issues that are especially important. This tool was used to screen the technologies identified to date. BIT and integrated electronics, software support, and cryogenic refrigeration technologies all have been indicated as having significant impact upon SDS support.

<u>Task 205. Supportability and Supportability-Related Design Constraints.</u> The supportability analysis, as with the previous tasks, focused on one ground-based system, one space-based system and software supportability, design constraints and risks. Subtasks included:
- Supportability characteristics identification;
- Supportability cost, readiness objectives, benefits and risks;
- Supportability design constraints;
- NATO equipment adoption constraints;
- Reliability-centered maintenance (RCM) implementation assessment;
- Strategies and techniques for software supportability design

This task was the first that utilized logistics computer models for a significant part of the analysis process. Relatively simple, spread sheet-based models, were used to conduct a Front-End Analysis (FEA) of SBI and ERIS. These models, one tailored for space-based assets and one for ground-based, provided outputs for resource requirements and costs by life-cycle phase and logistics element. Limited sensitivity analyses could be conducted by varying certain system inputs (e.g., system size, system mass, reliability, launch costs) and observing the impact on resource consumption and costs.

These models had serious limitations, such as the inability to calculate results for multiple orbital replacement units (ORUs) and no capability to examine alternate maintenance pipelines. Despite these limitations life-cycle costs associated with replacing failed satellites, particularly for a large constellation in low earth orbit, far exceeded projected costs for accomplishing on-orbit maintenance and servicing. During the course of the analysis, the models were rewritten in Turbo Pascal, and many of the previous limitations have been overcome.

The model results suggested several general supportability design strategies including modular design, standard electrical and fluid interfaces, inter-system commonality where appropriate, system reliability consistent with the support concept and system availability requirements, incorporation of BIT to the ORU level, and design of ORUs to minimize MTTR. To accomplish these goals, early establishment and utilization of a Configuration Control Board (CCB) was recommended. It was further recommended that the CCB institute procedures for value engineering change proposals to enlist the active participation of industry in improving supportability. Due to the high concentration of electronics (which usually exhibit a random failure pattern over extended periods) in the space-based systems, scheduled maintenance was found to be not cost effective. FEA results strongly suggested that attempts to improve system reliability beyond an MTBF of about four years (for a large low-Earth orbit (LEO) constellation) would not be cost effective. It appeared that the only practical method to accomplish high system reliability was through redundancy, which could sharply increase mass and cost.

Finally, it was determined that design should emphasize the lowest subsystem failure rate practicable, consistent with cost and readiness requirements. However, it was found to be even more important to design subsystems so that one or two subsystems do not force the maintenance interval. The cost effectiveness of supporting higher and smaller constellations, such as space-based surveillance and tracking system (SSTS) and boost surveillance and tracking system (BSTS), could not be conclusively shown at this analysis level.

A series of relatively general supportability actions were recommended for software development and follow-on supportability enhancement (e.g., modular program development, testing and validation processes, and configuration control procedures/approaches) (Note: This is an ongoing special study area, for SDS, that is applicable to most LSA tasks.) The following specific recommendations were made:
- Utilize standardized computer models to determine and validate supportability requirements/factors and to conduct tradeoff analyses.
- Establish a system that ensures contractor interface for interacting systems.

(Note: These issues are representative, and are being modified and supplemented as part of the iterative LSA process.)

<u>300 Series Tasks</u> The 300 series tasks continue the logistics analysis process. Using the foundation of the LSA Strategy and the LSAP and the framework developed in the 200 series tasks,

these next tasks complete the support analysis structure. This series of tasks identifies both the operational and support functions of the SDS, develops support alternatives, and conducts tradeoff analyses to determine the support alternative(s) with the best balance of supportability, affordability and operational effectiveness.

Task 301. Functional Requirements Identification. This task was begun by identifying the major functions that all the known/proposed SDS systems would be required to perform (Figure 3). This identification was then detailed into diagrams containing the system-level core functions and tasks for both operations (Table 1) and support (Table 2). Using the core data, additional system-element specific operations and support function and task diagrams were developed. The system elements, functions, and tasks were analyzed to determine unique functions and tasks and those that may present high risk in terms of supportability. This relatively routine analysis of the individual system elements, combined with the results of Task 205, provide the basis for determining the support alternatives.

Task 302. Support System Alternatives. Information gained from the preceding tasks allowed construction of a support alternatives tree (Table 3). The tree was developed to address both the supportability constraints from LSA Task 205 and the system functions and tasks identified in LSA Task 301. Software support alternatives were addressed in a complementary, but separate, analysis because software crossed the artificial system boundaries of space- and ground-based systems.

The initial analysis effort commenced with a review of the alternatives tree and resolved questions about the feasibility, apparent cost, and differences between the alternatives. Out of the process four support alternatives were selected for further analysis: (1) direct replacement of failed satellites; (2) on-orbit support through the direct launch of earth-based maintenance and servicing systems; (3) on-orbit support using with in-ring space-based support platforms (SBSP); and (4) on-orbit support using fewer numbers of SBSPs, differentially regressing with respect to the space assets, to support multiple rings. In all cases, it was assumed that the first response to failure would be the use of telemetry to effect repair and that BIT was sufficiently accurate

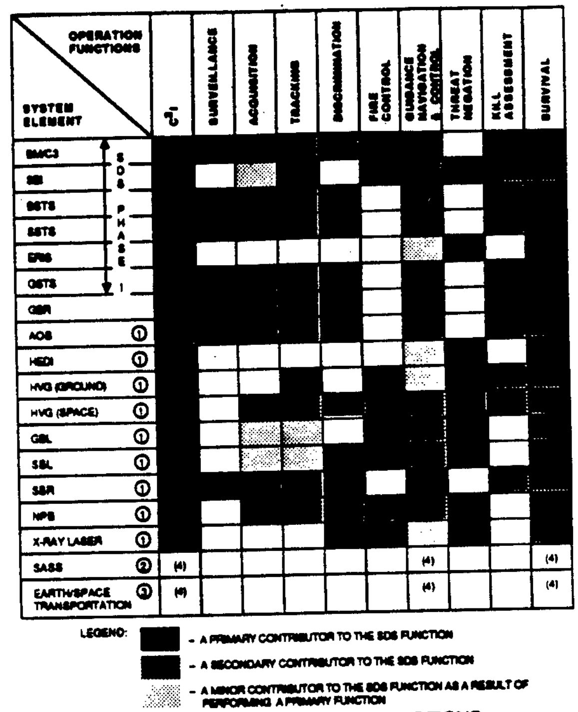


FIGURE 3 - SYSTEM LEVEL FUNCTIONS TO BE ACCOMPLISHED BY SDS

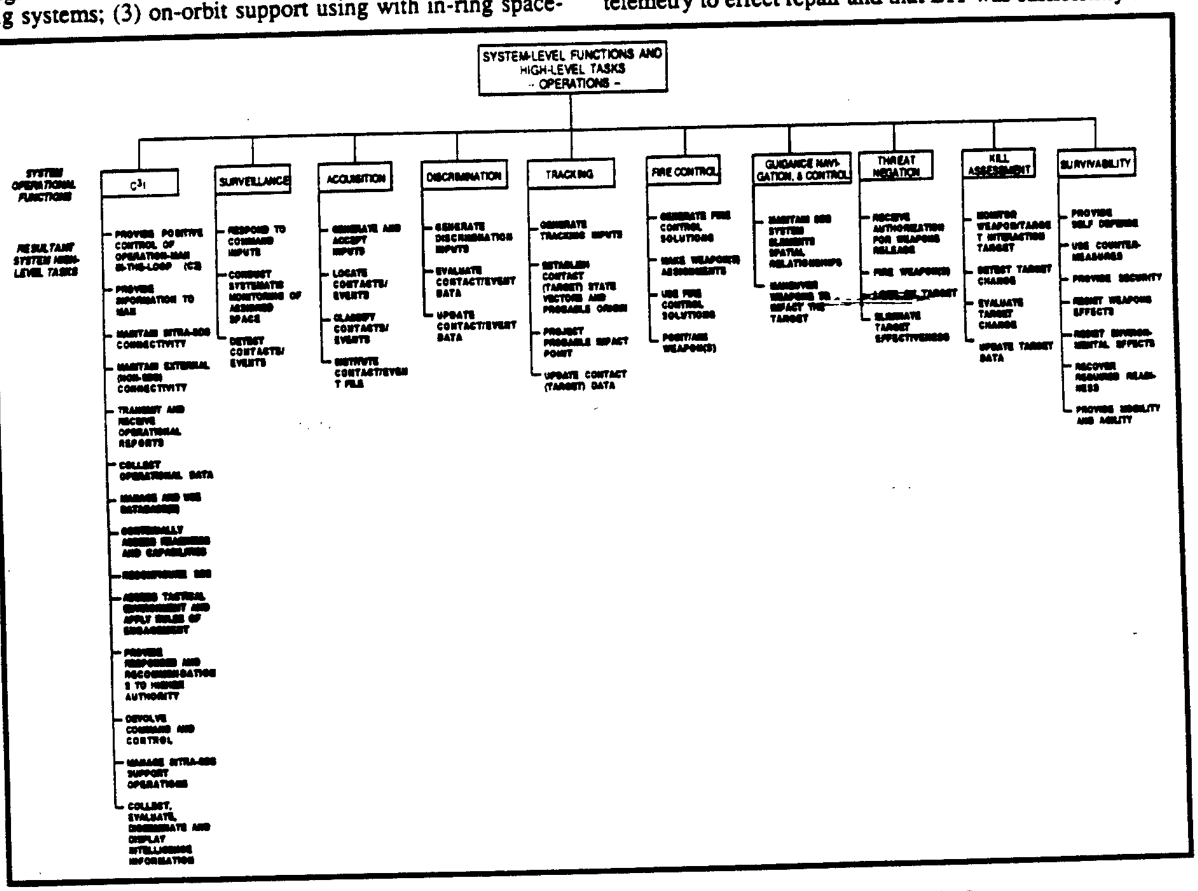


TABLE 1 - SYSTEM LEVEL FUNCTIONS AND HIGH-LEVEL TASKS - OPERATIONS

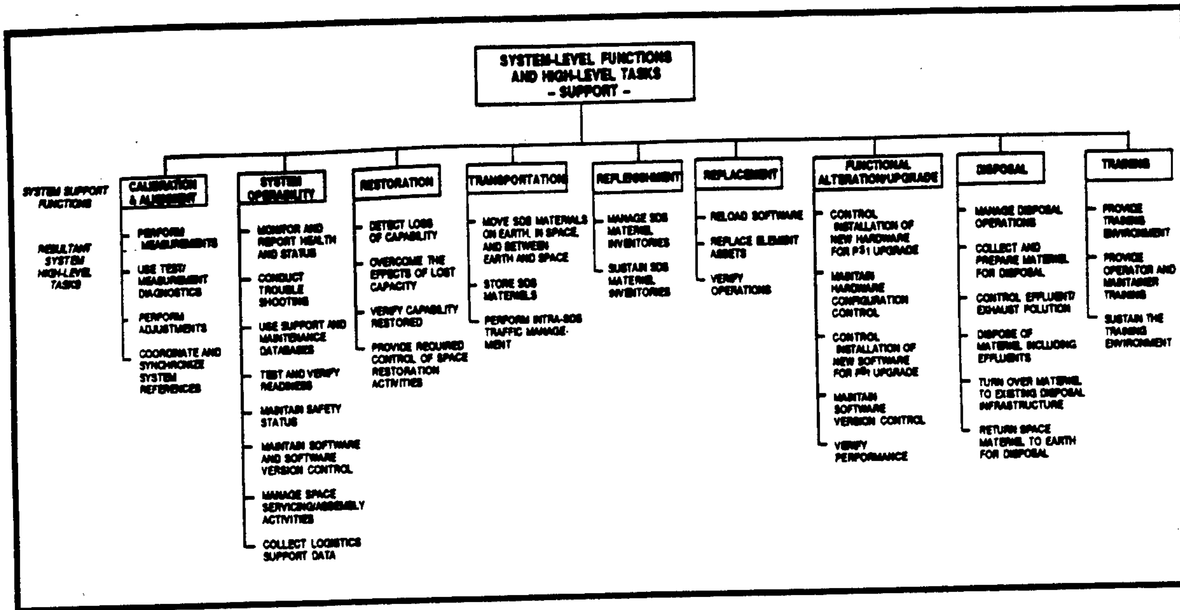


TABLE 2 - SYSTEM LEVEL FUNCTIONS AND HIGH-LEVEL TASKS - SUPPORT

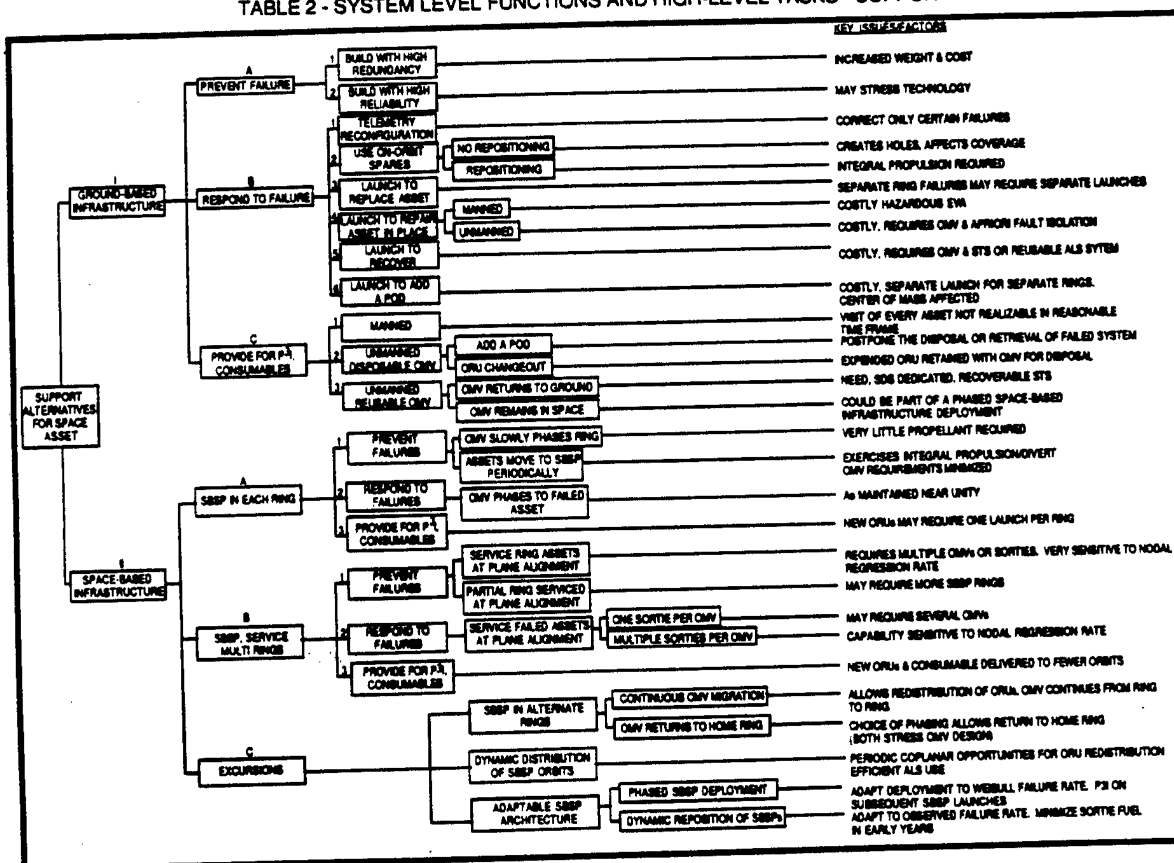


TABLE 3 - SUPPORT CONCEPT TREE

and reliable that the failure would be indicated to the ORU (box) level. Following these initial qualitative evaluations, computer model results (e.g., the FEAs from Task 205) were reviewed and more advanced models were utilized to confirm the feasibility of the support alternatives. The more advanced models were Space Assets Support System Analysis Model (SASSAM) and the Air/Ground Tradeoff (AGTO) model. Both are deterministic models, developed by DRC to support the SDS LSA effort. The AGTO is an expansion of the Air/Ground FEA, with the addition of a detailed maintenance pipeline, and the accrual of costs in accordance with current Army practice. SASSAM models the numerous variables associated with the orbital maneuvering necessary to perform on-orbit maintenance and servicing. In the process of analyzing selected space-based support alternatives, an additional concept was developed where SBSPs at two different altitudes effectively "sandwiched" SBI and regressed in a way that they could service both SBI and SSTS (details of the analysis conducted using SASSAM are contained in "Cost Effectiveness of On-Orbit Servicing for Large Constellations"[1]). No alternative appeared to offer a near-term, cost-effective or feasible approach to support the small BSTS constellation in geosynchronous orbit. Results of this analysis referred four alternatives to Task 303 for tradeoff analyses; direct launch of maintenance and servicing from the ground would intuitively fall between direct replacement of satellites and on-orbit maintenance and servicing. Four software support alternatives were selected for tradeoff analysis in Task 303; (1) development contractor support; (2) other contractor support; (3) government support; and (4) any combination of the above.

Task 303. Evaluation of Alternatives and Tradeoff Analysis. This task involved quantitative and qualitative evaluations of the support concepts developed in Task 302. Trade studies were conducted with an objective of identifying the most cost-effective alternatives for supporting the ground and space-based system elements and SDS computer resources, particularly software. As previously stated, this paper is limited to a discussion of the analysis in regard to space-based assets; through this analysis the cost effectiveness of on-orbit maintenance was confirmed. All three on-orbit support alternatives were very close in cost effectiveness**, but continuing analysis should indicate if any of the alternatives is clearly superior.

Task 205 FEA results indicated that on-orbit maintenance/servicing was the most cost-effective approach to supporting large constellations in LEO; initial SASSAM results confirmed this coarse result. Figure 4 indicates LCC curves for the various support alternatives, at different launch cost extremes, over a representative 20-year system element life-cycle. The figure shows that on-orbit support using SBSPs offers the lowest LCC. However, the costs for nodal regression and the "sandwiching," or "excursions" concept, discussed briefly above, are close enough that additional analysis was warranted. A detailed discussion of this analysis is contained in the previously cited paper "Cost Effectiveness of On-Orbit Servicing for Large Constellations."

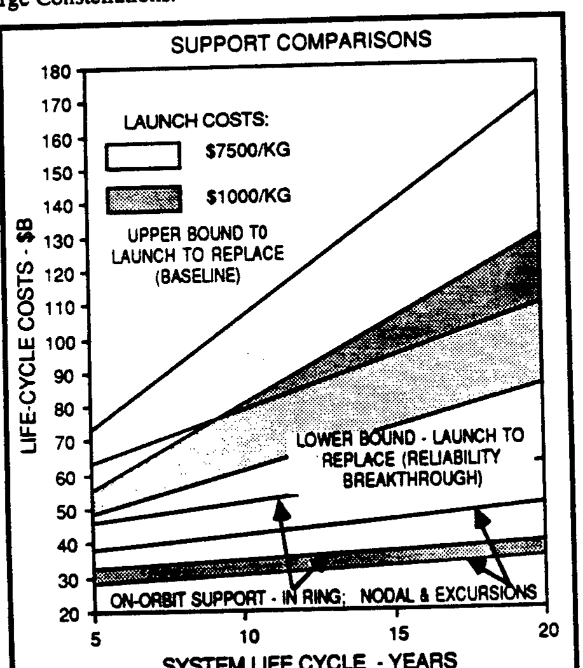


FIGURE 4 - LCC FOR VARIOUS SUPPORT CONCEPTS

A review of the assumptions initially used in the SASSAM modeling effort suggested that extending the delay time between servicing evolutions might reduce costs and still allow for maintaining a minimum required constellation notional availability, $A_c$, of 95 per cent. To test this hypothesis, a series of model runs was made to determine the sensitivities of availability, LCC and operations and support (O&S) costs, for SBI and SSTS, to changes in service intervals (delay), and to certain other input variables (e.g., MTBF, number of SBSPs, and on-orbit operational spare satellites). Essentially all other parameters (e.g., constellation size (except for spare satellites), altitude, mass, and numbers and capabilities of launch vehicles) were held constant.

** Cost source data was selected from the range of data available from government and industry and cost output should be used for comparison purposes only.

To facilitate the analysis of LCCs, SASSAM-generated data were entered on a spreadsheet and Figures Of Merit (FOM) were calculated. The FOMs are (1) $A_c$ related to O&S costs, and (2) $A_c$ related to LCC. LCCs for these alternatives were driven to a large degree by the acquisition costs for the SBSPs, in addition to the O&S costs. The use of FOMs allowed extremes to be quickly eliminated, and the analysis to be focused on the most promising alternatives. Representative results are shown in Table 4. When two or more alternatives are compared, LCCs and O&S costs must be checked in conjunction with the FOMs to determine the preferred alternative, especially when the alternative FOMs are close.

Analysis of support concepts for an SBI with a 3.3 year MTBF showed that in-ring placement of SBSPs resulted in superior FOMs. If system MTBFs were increased to 6 years, the nodal regression concept would produce a higher O&S FOM. However, the LCC FOM would still be more favorable with in-ring support. Comparison of in-ring and nodal regression concepts for the higher SSTS constellation resulted in even closer LCCs, possibly reflecting the increased MTBFs for this system element (Table 4). Additional qualitative analysis suggested that the "sandwich" approach, serving both SBI and SSTS constellations, would be even more cost effective since fewer SBSPs would be required (this has not been confirmed quantitatively as of this writing). Despite the number of model runs and the variations in maintenance delay and MTBF, no more definitive results have been achieved as of this writing.

Earlier analyses varied SBSP size as a multiple of a baseline for various support alternatives, with SBSP cost being directly proportional to size. Because the acquisition cost of these support platforms and the cost of placing them in orbit were among the cost drivers for the support alternatives, a more refined estimate for SBSP characteristics (e.g., mass and service life) was required. To determine these characteristics, recent, industry-provided SBI subsystem reliability data was used as a basis for formulating an efficiently sized SBSP. Using the data, a spread sheet was devised that calculated subsystem failures per year. Certain subsystems were subjectively eliminated as ORU candidates and the remaining subsystems were assigned a postulated number of ORUs. ORU failures per year were then calculated (Table 5). Using the average annual number of ORU failures and an average mass of 90 kg, an annual ORU mass-to-orbit requirement was calculated (Table 6). The results include a mass factor of 100 per cent for consumables and a tare fraction of 15 per cent, since industry data was not available for these materials. This adjustment allowed a more conservative projection of the support mass requirements for a specified time.

For purposes of determining total mass-to-orbit requirements, industry figures were used for an SBSP with an Orbital Maneuvering Vehicle/Smart Front End. The number of SBSPs launched to support SBI was then set at three, four, six, and eight and corresponding servicing loads (ORUs plus consumables) were developed (Table 7). Increasing the number of SBSPs increased the annual average mass to orbit and, in view of the direct relationship between mass to orbit and O&S cost, costs also presumably increased. LCC and O&S Costs will be lower, although the required $A_c$ may not be as readily maintained as with an SBSP in every ring. This result, based upon calculated values for SBSP, suggests that nodal regression is a superior method, from a cost effectiveness standpoint, for supporting on-orbit assets. Nodal regression also fits well with the "sandwich" excursion since analysis indicates only modest increases in SBSP mass, and no increase in numbers, would be needed to support the smaller and more reliable SSTS constellation.

| | SBI | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | MTBF (YR) | DELAY (DAYS) | Ac= % Up | ACQCOST $B | O&S COST $B | LCC $B | FOM= Ac/O&S | FOM= Ac/LCC | SBSP | SRVCR | SPARE/ RING |
| **DIRECT REPLACE** | | | | | | | | | | | |
| | 3.3 | 64.00 | 95.00% | $16.10 | $63.30 | $79.40 | 1.50 | 1.20 | NA | NA | NA |
| | 6.0 | 115.00 | 95.00% | $23.00 | $49.60 | $72.60 | 1.92 | 1.31 | NA | NA | NA |
| **IN-RING SERVICING** | | | | | | | | | | | |
| Bi-Prop | 3.3 | 64.00 | 95.00% | $16.10 | $11.32 | $27.42 | 8.39 | 3.46 | 1/RING | 2/RING | 0 |
| Bi-Prop | 3.3 | 12.30 | 99.00% | $16.10 | $11.43 | $27.53 | 8.66 | 3.60 | | | |
| Bi-Prop | 3.3 | 24.80 | 98.00% | $16.10 | $11.36 | $27.46 | 8.63 | 3.57 | | | |
| Bi-Prop | 3.3 | 37.60 | 97.00% | $16.10 | $11.34 | $27.44 | 8.55 | 3.53 | | | |
| Bi-Prop | 3.3 | 50.70 | 96.00% | $16.10 | $11.33 | $27.43 | 8.47 | 3.50 | | | |
| **NODAL REGRESSION** | | | | | | | | | | | |
| W/O On-Orbit Spares | 3.3 | 198.35 | 91.85% | $16.10 | $11.73 | $27.82 | 7.83 | 3.30 | 6 | 2 | 0 |
| W/2 On-Orbit Spares | 3.3 | 198.35 | 95.48% | $17.50 | $12.56 | $30.05 | 7.60 | 3.18 | 6 | 2 | 2 |
| W/1 Spare & 8 SBSP | 3.3 | 148.76 | 95.79% | $16.80 | $12.86 | $29.66 | 7.45 | 3.23 | 8 | 2 | 1 |
| W/O Spares & 10 SBSP | 3.3 | 119.01 | 95.11% | $16.10 | $13.17 | $29.26 | 7.22 | 3.25 | 10 | 2 | 0 |
| W/1 Spare & 6 SBSP | 4.5 | 198.35 | 95.88% | $19.96 | $11.30 | $31.26 | 8.48 | 3.07 | 6 | 2 | 1 |
| W/0 Spares & 8 SBSP | 4.5 | 148.76 | 95.47% | $19.13 | $11.64 | $30.77 | 8.20 | 3.10 | 8 | 2 | 0 |
| W/1 Spare & 6 SBSP | 6.0 | 198.35 | 97.45% | $24.01 | $10.83 | $34.84 | 9.00 | 2.80 | 6 | 2 | 1 |
| W/0 Spares & 13 SBSP | 6.0 | 91.55 | 97.91% | $23.01 | $12.99 | $36.00 | 7.54 | 2.72 | 13 | 2 | 0 |
| | SSTS | | | | | | | | | | |
| | MTBF (YR) | DELAY (DAYS) | Ac= % Up | ACQCOST $B | O&S COST $B | LCC $B | FOM= Ac/O&S | FOM= Ac/LCC | SBSP | SRVCR | SPARE/ RING |
| **DIRECT REPLACE** | | | | | | | | | | | |
| | 3.3 | 64.01 | 95.00% | $2.18 | $9.24 | $11.42 | 10.28 | 8.32 | NA | NA | NA |
| | 20.0 | 135.00 | 98.19% | $18.48 | $11.95 | $30.43 | 8.22 | 3.23 | | | |
| **IN-RING SERVICING** | | | | | | | | | | | |
| Bi-Prop | 7.0 | 135.00 | 95.00% | $5.77 | $2.03 | $7.80 | 46.80 | 12.18 | 1/RING | 2/RING | 0 |
| Bi-Prop | 7.0 | 0.32 | 99.99% | $5.77 | $2.24 | $8.01 | 44.64 | 12.48 | | | |
| Bi-Prop | 7.0 | 25.80 | 99.00% | $5.77 | $2.03 | $7.80 | 48.72 | 12.69 | | | |
| Bi-Prop | 7.0 | 79.00 | 97.00% | $5.77 | $2.03 | $7.80 | 47.76 | 12.43 | | | |
| **NODAL REGRESSION** | | | | | | | | | | | |
| W/O On-Orbit Spares | 7.0 | 252.42 | 95.06% | $5.77 | $1.75 | $7.52 | 54.38 | 12.65 | 1 | 2 | 0 |
| W/1 On-Orbit Spare | 7.0 | 252.42 | 99.99% | $6.73 | $1.98 | $8.71 | 50.53 | 11.48 | 1 | 2 | 1 |

TABLE 4 - FIGURES OF MERIT FOR SUPPORT ALTERNATIVES - SBI AND SSTS

| | SUB-SYSTEM CUMULATIVE FAILURES YEAR OF OPERATION | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | 1st | 2nd | 3rd | 4th | 5th | 6th | 7th | CUM SUB-SYS FAIL | ORU/ SUB-SYS |
| **SUB-SYSTEM** | | | | | | | | | |
| AVIONICS/DPS | 1.16 | 2.38 | 3.67 | 5.04 | 6.50 | 8.05 | 9.73 | 10 | 2 |
| BATTLE MANAGEMENT/C3 | 2.48 | 5.10 | 7.86 | 10.79 | 13.92 | 17.26 | 20.84 | 21 | 2 |
| COMMUNICATION | 1.16 | 2.38 | 3.67 | 5.04 | 6.50 | 8.05 | 9.73 | 10 | 3 |
| CRYOGENICS | 0.83 | 1.70 | 2.62 | 3.60 | 4.64 | 5.75 | 6.95 | 7 | 3 |
| ELECTRICAL POWER | 0.99 | 2.04 | 3.15 | 4.32 | 5.57 | 6.90 | 8.34 | 8 | 2 |
| FIRE CONTROL & SENSORS | 2.48 | 5.10 | 7.86 | 10.79 | 13.92 | 17.26 | 20.84 | 21 | 4 |
| GUIDANCE & CONTROL | 1.32 | 2.72 | 4.19 | 5.76 | 7.42 | 9.20 | 11.11 | 11 | 2 |
| INTERCEPTOR | 1.98 | 4.08 | 6.29 | 8.64 | 11.13 | 13.80 | 16.67 | 17 | 12 |
| MECHANISM | 0.50 | 1.02 | 1.57 | 2.16 | 2.78 | 3.45 | 4.17 | 4 | |
| PROPULSION | 0.66 | 1.36 | 2.10 | 2.88 | 3.71 | 4.60 | 5.56 | 6 | |
| SEPARATION | 1.32 | 2.72 | 4.19 | 5.76 | 7.42 | 9.20 | 11.11 | 11 | |
| THERMAL CONTROL | 0.50 | 1.02 | 1.57 | 2.16 | 2.78 | 3.45 | 4.17 | 4 | |
| STRUCTURE | 0.02 | 0.02 | 0.02 | 0.02 | 0.02 | 0.02 | 0.02 | 0 | |
| SUB-SYS FAIL CUMULATIVE | 15.39 | 31.61 | 48.75 | 66.94 | 86.31 | 107.01 | 129.23 | 129 | 30 |
| DELTA/YEAR | | 16.23 | 17.14 | 18.19 | 19.37 | 20.70 | 22.22 | | |
| | ORU ANNUAL FAILURES | | | | | | | | |
| | | | | | | | | CUM FAIL ORUs | |
| **ORU FAILURES** | | | | | | | | | |
| AVIONICS/DPS | 2.31 | 2.44 | 2.58 | 2.74 | 2.92 | 3.12 | 3.34 | 19 | |
| BATTLE MANAGEMENT/C3 | 4.96 | 5.23 | 5.53 | 5.87 | 6.25 | 6.68 | 7.17 | 42 | |
| COMMUNICATION | 3.47 | 3.67 | 3.86 | 4.11 | 4.38 | 4.67 | 5.02 | 29 | |
| CRYOGENICS | 2.48 | 2.62 | 2.76 | 2.93 | 3.13 | 3.33 | 3.59 | 21 | |
| ELECTRICAL POWER | 1.98 | 2.09 | 2.22 | 2.34 | 2.50 | 2.67 | 2.87 | 17 | |
| FIRE CONTROL & SENSORS | 9.92 | 10.46 | 11.06 | 11.74 | 12.49 | 13.36 | 14.33 | 83 | |
| GUIDANCE & CONTROL | 2.65 | 2.79 | 2.95 | 3.13 | 3.33 | 3.56 | 3.82 | 22 | |
| INTERCEPTOR | 23.80 | 25.13 | 26.55 | 28.16 | 29.95 | 32.05 | 34.43 | 200 | |

TABLE 5 - ANNUAL ORBITAL ORU REQUIREMENTS TO MAINTAIN Ac OF .95

| | SBSP 3/ | SBSP 4/ | SBSP 6/ | SBSP 8/ |
|---|---|---|---|---|
| TOT SBSP ORU Kg | 6480 | 4860 | 3240 | 2430 |
| CONSUMMABLE MASS % | 6480 | 4860 | 3240 | 2430 |
| TARE FRACTION % | 1944 | 1458 | 972 | 729 |
| PAYLOAD MASS/SBSP | 14904 | 11178 | 7452 | 5589 |
| OMV & SFE MASS Kg | 10200 | 10200 | 10200 | 10200 |
| HOUSEKEEPING MODULE KG | 8306 | 8306 | 8306 | 8306 |
| LAUNCH MASS/SBSP Kg | 33410 | 29684 | 25958 | 24095 |
| TOTAL LIFE MASS Kg | 200460 | 237472 | 311496 | 385520 |
| LAUNCH MASS ANNUAL | 28637 | 33925 | 44499 | 55074 |

TABLE 6 - ANNUAL ORU MASS-TO-ORBIT REQUIREMENTS W/VARYING NUMBERS OF SBSPs

| SBSP ORU LOADING ALTERNATIVES | | | | | |
|---|---|---|---|---|---|
| 3 SBSP 3.5 YR LIFE | ANN ORU | 3.5 YR | ORU/PLAT | ORU Kg/P | ORU DELTA |
| AVIONICS/DPS | 3 | 9.73 | 3 | 270.00 | -1 |
| BM/C3 | 6 | 20.84 | 7 | 630.00 | 0 |
| COMMUNICATION | 4 | 14.59 | 5 | 450.00 | 0 |
| CRYOGENICS | 3 | 10.42 | 3 | 270.00 | -1 |
| ELECTRICAL POWER | 2 | 8.34 | 3 | 270.00 | 1 |
| FIRE CONTROL & SENSORS | 12 | 41.68 | 14 | 1260.00 | 0 |
| GUIDANCE & CONTROL | 3 | 11.11 | 4 | 360.00 | 1 |
| INTERCEPTOR | 29 | 100.04 | 33 | 2970.00 | -1 |
| TOTAL KG/PLATFORM | | | | 6480.00 | |
| 4 SBSP 3.5 YR LIFE | ANN ORU | 3.5 YR | ORU/PLAT | ORU Kg/P | ORU DELTA |
| AVIONICS/DPS | 3 | 9.73 | 2 | 180.00 | -2 |
| BM/C3 | 6 | 20.84 | 5 | 450.00 | -1 |
| COMMUNICATION | 4 | 14.59 | 4 | 360.00 | 1 |
| CRYOGENICS | 3 | 10.42 | 3 | 270.00 | 2 |
| ELECTRICAL POWER | 2 | 8.34 | 2 | 180.00 | 0 |
| FIRE CONTROL & SENSORS | 12 | 41.68 | 10 | 900.00 | -2 |
| GUIDANCE & CONTROL | 3 | 11.11 | 3 | 270.00 | 1 |
| INTERCEPTOR | 29 | 100.04 | 25 | 2250.00 | 0 |
| TOTAL KG/PLATFORM | | | | 4860.00 | |
| 6 SBSP 3.5 YR LIFE | ANN ORU | 3.5 YR | ORU/PLAT | ORU Kg/P | ORU DELTA |
| AVIONICS/DPS | 3 | 9.73 | 2 | 180.00 | 2 |
| BM/C3 | 6 | 20.84 | 3 | 270.00 | -3 |
| COMMUNICATION | 4 | 14.59 | 2 | 180.00 | -3 |
| CRYOGENICS | 3 | 10.42 | 2 | 180.00 | 2 |
| ELECTRICAL POWER | 2 | 8.34 | 1 | 90.00 | -2 |
| FIRE CONTROL & SENSORS | 12 | 41.68 | 7 | 630.00 | 0 |
| GUIDANCE & CONTROL | 3 | 11.11 | 2 | 180.00 | 1 |
| INTERCEPTOR | 29 | 100.04 | 17 | 1530.00 | 2 |
| TOTAL KG/PLATFORM | | | | 3240.00 | |
| 8 SBSP 3.5 YR LIFE | ANN ORU | 3.5 YR | ORU/PLAT | ORU Kg/P | ORU DELTA |
| AVIONICS/DPS | 3 | 9.73 | 1 | 90.00 | -2 |
| BM/C3 | 6 | 20.84 | 3 | 270.00 | 3 |
| COMMUNICATION | 4 | 14.59 | 2 | 180.00 | 1 |
| CRYOGENICS | 3 | 10.42 | 1 | 90.00 | -2 |
| ELECTRICAL POWER | 2 | 8.34 | 1 | 90.00 | 0 |
| FIRE CONTROL & SENSORS | 12 | 41.68 | 5 | 450.00 | -2 |
| GUIDANCE & CONTROL | 3 | 11.11 | 1 | 90.00 | -3 |
| INTERCEPTOR | 29 | 100.04 | 13 | 1170.00 | 4 |
| TOTAL KG/PLATFORM | | | | 2430.00 | |

TABLE 7 - PLATFORM LOADING ALLOCATIONS W/VARYING NUMBER OF SBSPs

Task 501. Supportability Test, Evaluation and Verification. This task identified system-level supportability requirements to be assessed and related the requirements to support functions. The specific requirements for the task, as related to SDS, include the following:

- Identify SDS supportability requirements;
- Provide recommended supportability experiments;
- Develop a supportability test, evaluation, and verification (TEV) strategy;
- Develop a supportability assessment plan;
- Integrate the strategy and plan into the SDS Test and Evaluation Master Plan.

It was estimated early in the task analysis that no dedicated tests, evaluations, or verifications would be conducted for supportability assessment purposes. Rather, the system supportability assessments would be accomplished in conjunction with system operational TEV.

LSA Task 501 built upon the analysis of the previous LSA tasks to determine the most critical supportability issues which would require assessment. The issues were determined by use of the following criteria/goals:

- Achieve system readiness goals at an affordable life-cycle cost
- Ensure that supportability assessment issues influence SDS design
- Ensure that software is testable, maintainable and upgradeable

Following identification of the supportability issues, a Supportability Assessment Strategy was devised and a Supportability Assessment Plan was written to implement the Strategy. The plan addresses the system-level issues that must be thoroughly assessed to ensure the adequacy of the support system and the supportability of the hardware design. In addition to addressing supportability TEV organization, functions and reporting, the plan includes:

- Recommended support-related experiments;
- Software supportability assessment issues;
- Supportability test program limitations;
- Critical supportability issues;
- Supportability assessments combined with operational testing.

To ensure the Supportability Assessment Plan is available to all personnel involved in SDS supportability TEV, it has been integrated into the SDS Test and Evaluation Master Plan.

## Summary

LSA, performed in accordance with MIL-STD-1388-1A, is a disciplined, but flexible, approach to analyzing systems to improve supportability and affordability while maintaining or improving system operational readiness. The approach is also applicable to non-military systems, especially large, complex systems such as Shuttle "C" and Space Station.

With the foundation provided by a sound LSA Strategy and LSAP, and the bounding established by the 200 series tasks, SDS functions and tasks are being developed and analyzed, with support alternatives postulated. These support alternatives are joined with specific system elements, and analyses conducted to determine which support alternative(s) offer the best balance of cost and operational readiness.

Analysis has shown that SDS on-orbit support will be both feasible and cost effective. Maintenance of space-based assets will be enhanced through modularity, which will facilitate robotic removal and replacement of failed ORUs. Increasingly dependable BIT systems/indications will reduce the false removal rate. Cryogenic equipment technologies are advancing to meet the SDS requirements. Analysis is continuing to refine the elements involved with on-orbit maintenance, such as the following:

- ORU replacement factors;
- SBSP size and life-cycle;
- SBSP replenishment concepts and alternatives, and placement in relation to operational assets

MIL-STD-1388-1A provides an excellent foundation for the LSA process. Continuing this process, with the current cooperative input from industry, will result in a supportable, affordable SDS.

Reference

1. "Cost Effectiveness of On-Orbit Servicing for Large Constellations", by Dr. William Robertson, Mr. Jack Sliney and Mr. Joel Luna, AIAA 88-3519.