THE AIRCRAFT SUSTAINABILITY MODEL®

A SYSTEMS APPROACH TO SPARES MANAGEMENT

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GOVERNMENT CONSULTING

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Managers are often required to estimate the spare parts needed to sustain a system or a network of specialized equipment (e.g., a fleet of aircraft, a refinery complex, a power generation grid, or a communications network). Such systems typically are composed of many different yet essential components (structural elements, engines, electronics, hydraulics, etc.). When those components fail, they must be replaced or repaired with spare parts before the system can resume operations.

This document describes LMI's approach to answering a fundamental inventory management question: What spares are required to ensure my system's future operation?

To answer this question, LMI developed the Aircraft Sustainability Model® (ASM®) sparing model,[1] a system-oriented approach to spares management. The model is the result of more than 20 years of experience in inventory analysis and modeling. The model determines spares requirements based upon each item's explicit contribution to overall performance[2] of the system as well as the item's unit cost.

For complex, high-value, and mission-critical systems, the ASM sparing model is the perfect complement to many of today's more generalized service parts management (SPM) packages. As the following sections illustrate, the ASM sparing model provides managers with a robust, capable, and highly adaptable tool that is equal to the sparing challenges imposed by the most sophisticated systems.

Basic Scenario

The ASM sparing model is a flexible and adaptive modeling environment that allows extensive variation in the user-defined system and logistical scenario. Although some users focus the model on estimating spares for only the most critical items under constant (i.e., steady state) operating conditions, others consider every reparable item over a wider range (i.e., dynamic) of operating conditions. In either case, once the system and scenario are defined, the basic question remains the same: What mix of spare parts is required to keep the system at some desired level of operational availability for a specific scenario?

Method

The ASM sparing model employs a systems approach that combines probability theory and mathematical modeling to produce an optimal sparing solution. This means a solution in which no other mix of spares can provide greater, system-wide availability for the same cost, or, conversely, the same system availability for less cost (within the scope of the model assumptions and data). In fact, the systems approach, as implemented by LMI, does not produce merely one solution, but an entire range of feasible sparing solutions over possible inventory budgets.

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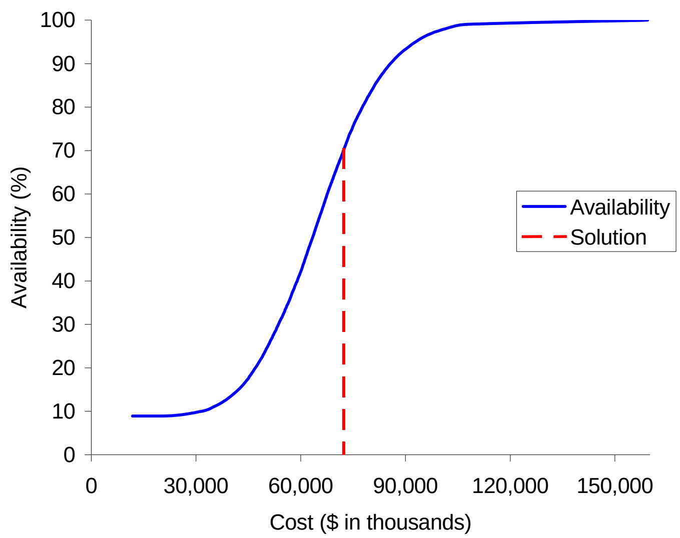
[1] The ASM family of models includes the Initial Spares Aircraft Availability Calculation™ (ISAAC™) and the Spacecraft Sustainability Model™ (SSM™). The ASM initially was created for aviation spares management (thus the name); however, it is adaptable to a wide range of other system types and industries.

[2] We measure overall system performance in terms of availability, that is, the probability the system is not inoperative due to the lack of a spare.

How does the systems approach work? It develops criteria for prioritizing spares procurement using a marginal analysis technique. Candidate buys are ranked in order of their benefit-to-cost ratios (i.e., the improvement in availability from adding the spare to inventory divided by the unit cost), then incrementally added to the sparing solution (in diminishing order) until a target budget or target availability[3] is reached.

Figure 1 illustrates a notional case in which inventory managers can determine their spares requirement by either defining a target system availability or defining a desired inventory budget. This systems approach produces a far more efficient and effective sparing solution than traditional item-oriented sparing approaches (typically about a 25 percent improvement in terms of system availability for a similar investment).

Figure 1. The Range of Possible Spares Solutions



Applications

The ASM sparing model is well-tested, and it is adaptable to a wide range of systems and environments. Although the system designs and operational environments are very different among the model's users, the same potential benefits exist for everyone—simultaneously increasing availability and reducing cost. The keys are suitably tailoring the approach to reflect the particular system operations, and making the model straightforward to use: A user enters an availability target or budget constraint, and the model computes the optimal mix of spares for the given target.

Details of the Systems Approach

An important aspect of the ASM sparing model's systems approach is the extension of the usual measures of inventory performance to measures that more directly relate to a particular system. For inventory performance, that measure is the number of backorders or unfilled demands for

[3] This definition of availability focuses only on spare parts and assumes other resources, such as personnel and maintenance facilities, are operating as planned.

spare parts. Although backorders can exist and be measured at any location in the supply system, the most important place to measure them is with the end user at the operating storage site.[4]

But backorders—even at the site level—are not the entire story. We must look further and consider the effect of backorders on the system. To some extent, this depends on the system's complexity, how dispersed the sites are, what policy and procedures exist for cannibalization, what subsystems have redundancy, as well as many other factors that must be taken into account. For management and planning, the system must also project future backorders that would result from actions taken today. Thus, we must project expected backorders[5] by item and derive the probable effect of those expected backorders on the system's availability.

Benefits of the System Approach

The system approach to sizing spares inventories has been adopted, in varying degrees, by each of the U.S. military services and has been official DoD policy since 1985. Its benefits are well-documented. For example, one study showed that using the ASM sparing model's weapon-system approach to compute wartime spares kits saved the U.S. Air Force 27 percent of its budget for the C-5 and C-141 fleets while still effectively supporting the mission of these aircraft. Another study showed that using LMI's Aircraft Availability Model (which also employs a weapon-system approach) achieved savings of $350 million out of a $1.76 billion replenishment spares budget without increasing the level of backorders.

System Characteristics

The ASM sparing model's basic systems approach considers a number of logistical and operational characteristics in addition to system availability and budget constraints. We briefly describe some of these characteristics below:

- *Item type*. The model focuses on items that affect availability and cost the most—the essential items. These are usually high-cost and highly indentured reparable items; however, the model can also consider less expensive (and sometimes less essential) consumable items that have a different set of item characteristics.
- *Indenture*. Each system has an indenture structure. Systems are composed of subsystems, called line replaceable units (LRUs); LRUs are composed of shop replaceable units (SRUs); SRUs are composed of lower indenture subSRUs; and so on. The system-oriented approach explicitly considers the cost and availability of spares at each indenture level.

  For example, a more expensive spare LRU has a significant impact on availability (when a spare LRU is available, the system is operational almost immediately), while the less

[4] Backorders at one of the higher echelons (i.e., the wholesale or centralized depot or contractor level) are an important management indicator, but they are only supportive of and subordinate to measuring capability to attain the ultimate goal of the inventory system.

[5] Item-expected backorders are a function of the balance between future item demand (rate of failure), item turn-around time (how quickly a failed item can be repaired and returned to service), and asset levels (existing spares inventory).

expensive SRU affects availability only indirectly. The availability of an SRU spare speeds the repair of its parent LRU and increases the likelihood of a serviceable LRU being ready for issue when it is needed.

- *Cannibalization*. The ability to consolidate broken LRUs ("holes") greatly improves system availability without increasing procurement costs.
- *Flexible operating scenarios*. The model can deal with many different operating scenarios and changes during the course of a scenario. For example, operating tempo may be steady state, dynamic, or both; repair and resupply may be suspended for a period; maintenance philosophy (e.g., cannibalization or not) may change, etc.
- *Multiple echelons*. The model trades off between storing spares at a central depot versus storing them at smaller retail sites (bases). Retail inventory is immediately available for onsite failures, but it is not available for other retail sites. Conversely, inventory from the depot is available, on a delayed basis, to all retail locations.
- *Common components*. As the name would imply, common components are applicable to more than one system type (e.g., on both F-15 and F-16 aircraft). The model considers the economies of scale gained for common components at multiple operating sites (that is, the total spares requirement is less when these economies of scale are taken into account than if each system type is considered independently).
- *Component stock considerations*. The model incorporates pre-specified user spares decisions when assets exist or orders have been placed previously.
- *Other item factors.* The model also considers a number of other item-specific factors, such as demand (failure) rates per operating hour, base and depot repair times, condemnation rates, transportation times, unit cost, quantity per application, and procurement lead-time.

Implementation of the System Approach

The ASM sparing model has integrated a state-of-the-art user interface, with high-speed, system-oriented spares computations and the database processing power of Microsoft® Visual FoxPro®. The model can determine spares requirements and evaluate the availability yielded by a predetermined spares mix.

Using the *requirements capability* of the ASM sparing model, the user enters a target (cost or availability) and the model calculates the optimal spares mix required to meet that target. The spares requirements can support new systems (e.g., initial provisioning) or existing systems (e.g., annual replenishment). The *evaluation capability* approaches the spares mix problem from the opposite direction. The model's evaluation mode enables the user to select a spares mix, and then calculate the system availability the specified mix provides under various conditions.

The ASM sparing model also provides spares analysts with the following capabilities:

- *Library of previous runs* (input and output) *and archiving or retrieval capability*. The model maintains a library of previous runs for comparative analysis purposes. The archiving and retrieval capability gives the analyst an easy way to save and restore spares analyses (model output) along with related item-level information (model input) in user-specified locations.
- *Sensitivity analysis capability* (global change). The model lets the user easily analyze the impact of input data changes upon output results. One can easily alter all or some of the item input. For instance, an analyst can increase all demand rates by 10 percent, or increase only the demand rates for items that cost more than $200,000.
- *Ease of analysis*. Through its database interface, the model permits the user to easily view weapon-system databases with large numbers of items. For instance, a user can select which data fields to view by checking them from an inclusive list. The model then displays and prints only those selected fields in a tabular form. When any item field header in the table is selected, the model sorts the data so the user can immediately identify the worst (or best) performing items.
- *Comparative analysis*. The model allows the user to compare a variety of input and output data at both the item and system levels. For instance, an analyst can compare any two model-generated spares requirements for the same weapon system. By simply selecting the two previous model results, the model presents a side-by-side comparison of the spares requirements, which can also be sorted so that the items are shown by order of increasing or decreasing differences.
- *Interactive and batch modes of operation*. The interactive mode allows customers to easily conduct sensitivity analyses on key factors in order to assess their impact on operations. The batch mode is intended for a production setting and runs without user intervention.
- *Variable data-intensive modes of operation*. Based on data availability, ASM sparing model users can select either a “standard” or “limited” module to optimize spares mixes. The standard module calculates spares for complex situations that require detailed data—such as levels of indenture, percentage of commonality, and quantity per assembly. If some of that information is not available, or is too expensive to obtain, the model has another module that operates on a more limited data set.

Experience

Service parts management solutions typically provide a number of “tactical” and “execution” features for day-to-day supply management that the ASM sparing model does not perform. When it comes to developing the proper spares mix for a complex and changing environment, however, LMI’s ASM sparing model is the industry leader for readiness-based (i.e., availability) sparing (RBS) solutions.

In a sense, RBS experience is analogous to the difference between a medical general practitioner and a specialist. The general practitioner can cure many ailments; but when it comes to a critical operation, it is the specialist (with the most experience and knowledge) that you want call. The following are among the key differentiators in LMI's experience and knowledge:

1. *Model maturity*. LMI has been developing RBS models for more than 30 years (with the ASM sparing model benefiting from more than 20 years of development and application history). The insight into customer needs that LMI has gained over the past 30 years has shaped the model's capabilities. Furthermore, the longevity of the user base—which literally spans decades—provides irrefutable proof of the ASM sparing model's usefulness.
2. *Breadth of applications*. The ASM sparing model has been a proven standard in the aerospace and defense RBS marketplace for many years. The number of years our long-term clients have been using the model attests to this longevity: the U.S. Air Force (more than 20 years), the Israel Air Force (13 years), and NASA (9 years).

   The U.S. Air Force uses the ASM sparing model to assess the readiness of its combatant units and to determine (i.e., size) their deployment spares packages. Aircraft that deploy to support the Global War on Terrorism are taking spares kits built upon the model's recommendations. LMI also adapted the model for sparing the space shuttle, space station, and preliminary spacecraft designs for our return to the moon.
3. *Validation and verification*. We have validated the ASM sparing model against many other RBS packages, and with several supply chain simulations, to ensure its accuracy. The fundamental RBS theory underlying the model was extensively tested by the U.S. Air Force through a series of deployment kit flyouts: Coronet Warrior I (F-15s), Coronet Warrior II (F-16s), and Coronet Warrior III (A-10s). The results of these flyouts were used to validate the value of using RBS logic for computing a squadron's wartime spares requirements.
4. *Industry and academia review*. The ASM sparing model's underlying RBS computational logic has been well documented in the open literature, and, therefore, widely evaluated by practitioners and academics.

   From the practitioner perspective, the evolution and development of RBS computational logic has been documented in a number of LMI studies and reports. In addition, LMI sponsored Dr. Craig Sherbrooke's textbook, *Optimal Inventory Modeling of Systems,*[6] which documents in great detail RBS inventory modeling theory and application.

   From an academic perspective, many fundamental RBS breakthroughs have been published in top-tier research journals, such as *Management Science* and *Operations Research*. Before an article appears in these prestigious journals, the work undergoes extensive scrutiny and multiple reviews by highly qualified peer "referees."

[6] Craig C. Sherbrooke, *Optimal Inventory Modeling of Systems: Multi-Echelon Techniques*, John Wiley and Sons, New York, 1992.

5. *Team size and experience*. The LMI Math Modeling Group has more than 600 combined years of general DoD logistics experience, and more than 250 years of specialized RBS inventory modeling experience.
6. *Adaptability and robustness*. The ASM sparing model is a robust, highly-adaptable, and sophisticated sparing tool ideally suited to answering complex budgetary and availability challenges. The model can serve as the perfect "specialist" plug-in to complement the tactical and execution capabilities of many other SPM packages available in the marketplace.

   The largest ASM sparing model installation, to date, is the U.S. Air Force implementation. Currently, more than 45 different weapon systems across 586 different spares kits that support more than 3,000 aircraft use the model each month to assess wartime readiness and determine what spares to take to war.

Conclusion

The ASM sparing model focuses on doing one thing very well: Computing availability-based RBS stockage recommendations for critical systems. The model is not a fully featured, integrated SPM solution. Rather, it is a robust, highly adaptable and sophisticated analytical tool that is expressly designed for answering complex budgetary and availability challenges. In this role, the ASM sparing model is the perfect complement to the tactical and execution capabilities of many other SPM packages.

In summary, there are five key takeaways regarding the ASM sparing model:

- It expresses the benefit of buying a particular mix of spares in terms of its effect on overall system availability.
- It takes into account the cost as well as the benefit of buying a particular mix of spares.
- Given a level of spares funding, it maximizes the capability for the given funding constraint.
- It produces a range of optimal spares—a mix of spares that provide the maximum performance of the complete system for a fixed level of funding, or costs the least for a specified level of system performance.
- It has been extensively and successfully used in a wide variety of sparing environments: initial system fielding, steady-state (peacetime) operations, and dynamic (wartime) deployments.

Finally, LMI has the breadth and depth of experience necessary to help our clients successfully overcome their most complex inventory management challenges.