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A READINESS ANALYSIS FOR THE ARGENTINE AIR FORCE AND THE BRAZILIAN NAVY A-4 FLEET VIA CONSOLIDATED LOGISTICS SUPPORT

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ABSTRACT

The Argentine Air Force and the Brazilian Navy recently added the Douglas A-4 Skyhawk aircraft to their military services. Each country maintains its own limited repair facility and spare parts inventory. Major repair work (depot-level maintenance) must be sent to the manufacturers in the United States, and the long repair cycle times adversely affect military readiness. It is critical to implement an effective spare parts management system to compensate for such long repair cycle times. We developed a simulation model to study the impact of consolidating aviation component spare parts inventory management and reducing transportation cycle times. Our results indicate that both countries will greatly benefit if they collaborate on the inventory management of their A-4 fleet maintenance. Their benefits will be significantly increased if they change the sea transportation mode to air transportation for transporting avionic components back and forth to the United States for repair.

1 INTRODUCTION

In 1998, the Argentine Air Force purchased thirty Douglas A-4 Skyhawk aircraft. That same year the Brazilian Navy purchased twenty A-4's for its operations from the aircraft carrier Minas Gerais (A-11). This was the first time that the A-4's were introduced to both countries. The addition of new aircraft requires new infrastructure for logistics support and maintenance. However this task cannot be accomplished in the short term, since both military services are under great pressure to reduce defense budgets and workforce levels due to economic recession. Argentina and Brazil have limited capability to repair complex avionic components, and they must rely on manufacturers in the United States for depot level maintenance. The long repair cycle times adversely affect military readiness. It is critical to implement an effective spare parts management system to compensate for such long repair cycle times.

Both Argentina and Brazil have strong incentives to collaborate to better manage their military operations. Argentina and Brazil have an interesting bilateral cooperation history, especially in economic and military issues. Since 1979, when respective military regimes resolved Paraguay's hydroelectric conflict by building the Itaipu Dam on the Parana River, an escalation of efforts and decisions have been successfully developed and implemented towards the stabilization of the economic cooperation and integration process. This integration covers not only economic issues such as a common economic market, but also educational and military cooperation. This close relationship is being reinforced by the concrete actions taken by the authorities of both countries at present and envisioning the future (Kacowicz 1999).

In this paper, we propose collaboration of the A-4 aircraft fleet maintenance between Argentina and Brazil. Successful implementation of the proposed ideas could encourage more collaboration of military affairs between these two countries.

2 AIRCRAFT MAINTENANCE AND REPAIRABLE ITEM INVENTORY MANAGEMENT

The maintenance of A-4 fleet for both Argentina and Brazil is similar to the United States Navy's three levels of maintenance: organizational level (O-level), intermediate level (I-level), and depot level (D-level). O-level maintenance is performed at the operational site (squadron), involving simple repairs and replacements of modular components to support its own operations. I-level maintenance involves more difficult repairs and maintenance, including the repair and testing of modules that have been forwarded from the O-level. I-level maintenance is performed ashore in the air stations or afloat in aircraft carriers. D-level maintenance ensures the continued flight integrity and safety of airframes and related flight systems throughout their service lives. (Blanchard 1998) This involves performing maintenance beyond the capabilities of the lower levels, usually on equipment requiring major overhaul or rebuilding of end items, subassemblies, and parts. The following is a brief description of the A-4 maintenance system.

When an aircraft fails, the faulty component (e.g., digital mission computer, or engine) is removed from the aircraft at the O-level and a spare part is obtained from an inventory location at the base and installed on the aircraft; thereby restoring it to full mission capability. If a spare part is unavailable, the aircraft must be grounded, thereby negatively affecting fleet readiness. The faulty component is forwarded to the I-level maintenance facility. Repairs beyond the I-level capability are forwarded to the D-level. The repaired components are shipped back to the spare parts pool at the inventory location. Currently both the Argentine Air Force and the Brazilian Navy maintain their own I-level maintenance facility, but D-level maintenance takes place in the United States. Thus those items requiring D-level maintenance must be shipped to the United States.

The D-level maintenance takes anywhere from three to six months including transportation delays. Since long turnaround times adversely affect the readiness of A-4 squadrons, it is critical to maintain adequate inventory levels for spare parts to maintain to compensate for long repair cycle times. However, budget constraints have pressure to reduce inventory levels since aviation spare parts are very expensive and have long acquisition lead times.

The goal of military logistics support is to maintain the highest possible readiness, commonly expressed as operational availability, A_0 = MTBM / (MTBM + MDT) = uptime / (uptime + downtime), where MTBM is the mean time between maintenance and MDT is the maintenance downtime that includes repair, transportation, and administrative/ logistics delay times. Intuitively, operational availability is the fraction of time a weapon system is operational or mission capable. Clearly, an operational availability can be improved by increasing MTBM (i.e., increasing reliability) or decreasing MDT (i.e., reducing maintenance cycle time) (Kang, Gue and Eaton 1998). In this paper we propose (i) spare parts inventory consolidation between Argentine and Brazilian aircraft maintenance, which provides better spare availability, thus reducing the chance of unnecessary grounding aircraft; and (ii) transportation time reduction for D-level maintenance to reduce MDT, which in turn will improve operational availability.

3 SIMULATION MODEL

3.1 Baseline Model Description

In this section, we describe the baseline simulation model developed in ARENA simulation language (Kelton, Sadowski and Sadowski 1998). Details of the model and additional analyses beyond what is described in this paper is available in Rodrigues and Karpowicz (1999). Sufficient data on avionic component reliability was unavailable from the Argentine Air Force or the Brazilian Navy since their A-4 fleet operation started in 1998, and both are still training the pilots and maintenance personnel. The Brazilian Navy is also in the process of upgrading equipment and remodeling the aircraft carrier Minas Gerais (A-11) to include I-level maintenance capability. The data presented in this paper was obtained from the Naval Aviation Depot-North Island, California and modified based on the projected flying hours and operating environments.

We consider two different types spare parts: line-replaceable unit (LRU) and shop-replaceable unit (SRU). An LRU is an avionic subassembly essential for the A-4 aircraft's primary flying mission performance. Examples of LRU's are digital mission computers and radar altimeters. Each LRU consists of several subcomponents called shop-replaceable units (SRU). Examples of an SRU include circuit cards and high voltage power supplies.

We have chosen five critical LRU's for our spare parts inventory analysis: Digital Mission Computer (LRU_1), Radio Altimeter (LRU_2), Air Data Computer (LRU_3), Inertial Navigation Unit (LRU_4), and Head up Display Unit (LRU_5). Both Argentina and Brazil have limited capability of repairing these electronic components, so the majority of repair work is performed in the United States.

We also consider two SRU's: Torque Drive Power Supply Module (a subcomponent of the Radio Altimeter (LRU_2), and will be referred to as SRU_2), and Sensor Assembly (a subcomponent of the Inertial Navigation Unit (LRU_4) and will be referred to as SRU_4). These two SRU's were chosen because they are the primary causes of LRU failures. For these LRU's, they do not have to send an entire LRU to the United States for repair in case of a specific SRU failure. The faulty SRU is removed from the LRU and replaced with an SRU from the spare parts pool. The LRU can be returned to the spare pool and only the faulty SRU is sent to the United States for repair. Table 1 presents the inventory level for each LRU spare parts pool and the two SRU's.

Table 1: Number of Spares for Each LRU/SRU for the Argentine Air Force and the Brazilian Navy

	LRU 1	LRU 2	LRU 3	LRU 4	LRU 5	SRU 2	SRU 4
Argentina	3	2	2	3	3	3	5
Brazil	2	3	3	2	2	7	5

Table 2 provides the mean time between failures of LRU's (in days). These numbers were based on the data obtained from the Naval Aviation Deport-North Island, California. We assume that the projected flying hours for each aircraft is 30 hours per month, and that the failure times follow an exponential distribution. We note that the mean time between failures (MTBF) of Brazilian aircraft is significantly lower since these aircraft operate from the aircraft carrier while the Argentine Air Force aircraft operate from a land-based air station. The carrier-based aircraft are more exposed to the sea elements of corrosion and have more stress from carrier takeoffs and landings.

Table 2: Mean Time between Failures (MTBF) of LRU's (unit: days)

	Argentine	Brazil
LRU_1	220.5	147.0
LRU_2	270.0	180.0
LRU_3	174.0	116.0
LRU_4	146.0	97.4
LRU_5	272.0	181.0

When an LRU fails, an RFI (ready-for-issue; i.e., good part) LRU from the spare parts pool is installed. The faulty LRU becomes an input to the I-level to be repaired and returned to the spare parts pool as an RFI item. The time for removal/installation of LRU is assumed to have triangular distribution with a minimum of 0.250 days, a mode of 0.375 days and a maximum of 0.500 days. Time for inspection to determine the appropriate level of maintenance (i.e., I-level or D-level maintenance) follows a uniform distribution with a lower bound of 0.125 days and a upper bound, 0.375 days. Table 3 provides the percentage of the LRUs at the I-level that are considered beyond capability of maintenance (BCM) and are sent to the United States for D-level maintenance.

When an LRU fails, if an RFI LRU is unavailable, the aircraft is grounded until one is available. The mean time to repair (MTTR) for each LRU at the I-level maintenance facility is presented in Table 4.

Table 3: Percentage of LRU's Sent to the U.S. for D-level Maintenance

LRU	Percentage of LRU's Sent to the U. S.
LRU_1	70%
LRU_2	88%
LRU_3	80%
LRU_4	66%
LRU_5	69%

Table 4: Mean Time to Repair (MTTR) for LRU's

LRU	MTTR (days)
LRU_1	1.04
LRU_2	0.41
LRU_3	1.12
LRU_4	0.36
LRU_5	1.73

All faulty SRU's are considered beyond capability of maintenance, and are shipped to the United States for repair. Table 5 presents the time spent when a faulty part is sent to (northbound) and from (southbound) the United States for repair using sea mode transportation. It takes longer time for northbound route than southbound because of an additional delay for warranty verification and document processing before sending the faulty part to overseas. We assumed that the distributions of the transportation times and D-level repair time follow the uniform distribution.

Table 5: Repair Cycle Times for D-level Sent to and from the U. S. using Sea Transportation

Activity	Time
Northbound route – administrative process (including warranty verification process time) plus transportation.	30 to 45 days
Southbound route– administrative process plus transportation.	20 to 40 days
Repairing LRU/SRU at D-level	30 to 90 days

3.2 Assumptions

The following assumptions were made to use the model.

- We are analyzing electronic components. Thus, we assume no need for preventive maintenance.
- The LRU/SRU's can be always repaired; no condemnations are considered.

- Spare units do not fail while in the spare parts pool.
- Aircraft failures are always due to only one of the LRUs. Consequently, LRUs do not fail at the same time.
- The I-level repair shop operates eight hours a day.
- There is a single point of destination in the United States and a single point of origin for LRU/SRU's transportation computations (for time and cost estimates).
- No cannibalizations are considered. Hence, the fleet operational availability may be less in the simulation model than in real circumstances, but we considered the fact that cannibalization increases the maintenance man-hours required to repair the aircraft and can induce malfunctions to an otherwise serviceable LRU through additional handling.

3.3 Results

We ran two scenarios; one for the Argentine Air Force and the other for the Brazilian Navy. Fifty replications were made for each scenario over a ten-year period, since it is reasonable to assume that the life cycle of military avionic components is 10 years. As shown in Table 6, the operational availability of the Brazilian Navy A-4 fleet is 83.98% and the Argentine Air Force, 86.58%. Since the Brazilian aircraft operates from the aircraft carrier, their operational availability is lower than the Argentine aircraft. Table 6 also shows the number of LRU/SRU's sent to the United States over the 10 year life cycle period, generated from the simulation. These values will be used for cost calculations in the next section.

4 INVENTORY CONSOLIDATION (COALITION MODEL)

4.1 Model Description

In this section, we discuss the embellishment of the baseline model described in Section 3. We added stock consolidation for spare parts inventory, i.e., the Argentine Air Force and the Brazilian Navy share spare parts inventory. There are two ways of implementing this inventory consolidation idea: *physical* consolidation and *virtual* consolidation. For physical consolidation, Argentina and Brazil maintain one inventory stock point. For virtual consolidation, they maintain inventory in two different locations but are capable of tracking the movements of parts in the system. Both methods would add additional transportation time that may or may not be significant. We did not include this delay in our simulation model. This model is referred to as the *coalition model*. The assumptions and the data are the same as the previous baseline model in Section 3, except that the coalition model assumes one spare parts inventory for both Argentina and Brazil. The number of spare parts to be kept at the consolidated stock point for each LRU/SRU is as shown in Table 7. These numbers are the sums of the existing inventories of LRU/SRU's for both countries.

Table 6: Number of LRU/SRU's Sent to the U. S. for D-level Repair, and the Average Operational Availability over 10-year Life Cycle

	Argentine	Brazil
LRU1	58	53
LRU2	53	51
LRU3	85	89
LRU4	87	115
LRU5	43	39
SRU2	8	8
SRU4	25	31
TOTAL LRUs	326	347
TOTAL SRUs	33	39
Operational Availability	0.8658	0.8368

Table 7: Number of Spare LRU/SRU's for the Coalition Model

	LRU 1	LRU 2	LRU 3	LRU 4	LRU 5	SRU 2	SRU 4
Number of Spare Parts at Consolidated Stock Point	5	5	5	5	5	10	10

4.2 Results

After 50 replications, the results show an increase in the operational availability from 83.97% and 86.57%, for the Brazilian and Argentine fleet, respectively, to 88.84%, for both fleet operating under the coalition model. It implies that Brazil will have an additional 0.973 aircraft [= 20 * (0.8884 - .8397)], and Argentina will have an additional 0.678 aircraft [30 * (0.8884 – 0.8658)] by sharing their spare parts. We may also state that at a given desired operational availability, the consolidated stock point requires fewer spares than two individually managed stock points.

The simulation results show the advantages of operational availability for the coalition model. To implement the stock consolidation described in the coalition model, Argentina and Brazil should be willing to develop a total asset visibility department that can keep track of avionic components in the system. Implementation of such organizational changes is the subject of further studies.

5 COALITION MODEL WITH REDUCED TRANS-PORTATION TIME

We ran the coalition model again, but this time we reduce the transportation time to analyze the impact on the operational availability of the A-4 fleet.

5.1 Transportation Time Reduction

The models discussed in the previous sections used sea mode transportation. These transportation times include administrative process delays and delivery time. Since the sea transportation is the main contributor of long cycle times and a readiness degrader, we propose a reduction of transportation time by changing to air transportation mode. Table 8 shows the estimated cycle times for the repair cycle times for D-level maintenance. Uniform distribution is assumed in the simulation run for these repair cycle times.

Table 8: Repair Cycle Times for D-level Sent to and from the U. S. Using Air Transportation

Activity	Time
Northbound route –administrative process (including warranty verification process time) plus transportation.	10 – 15 days
Southbound route– administrative process plus transportation.	8 – 13 days
Repairing LRU/SRU at D-level in the U. S.	30 – 90 days

We have collected cost and delivery time data for air transportation from the survey of domestic and international freight forwarders. Table 9 shows the average cost of transportation by express air mode (2 day delivery) for each LRU/SRU based on weight and size including insurance and door-to-door delivery service.

5.2 Results

After 50 replications, faster transportation times (air transportation instead of sea) will increase operational availability of the fleet by approximately 6% (from 88.9% to 95.0%). This represents having an additional 3.5 aircraft [3.5= 50*(0.95034–0.88838)] without increasing the number of spare parts. A simple calculation of the total air transportation cost over 10-year period is less than one million dollars, which is calculated by multiplying the number of LRU/SRU's transported to the United States in Table 4 by the transportation costs shown in Table 9. The benefit of having an additional 3.5 aircraft far exceed the extra transportation cost considering fact that each aircraft costs more than $6 million dollars.

Table 9: Cost of Express Air Delivery of LRU/ SRU's from and to the U. S. for Repair. (Unit: US $)

LRU/ SRU	Express Air Delivery + Insurance
LRU_1	$1,401
LRU_2	$432
LRU_3	$1,396
LRU_4	$1,587
LRU_5	$1,589
SRU_2	$277
SRU_4	$277

Improvement in operational availability through the reduction in transportation time can be explained by Little's Law (1961); faster transportation time reduces pipeline inventory at the repair shop. It implies that more spare parts at the inventory stock point are ready for the fleet, thus unnecessary aircraft grounding awaiting for spare parts is reduced. Figures 1 and 2 show the result. Figure 1 presents the simulation results of the number of grounded aircraft due to the shortage of each LRU over a 10-year period using slow sea transportation. Figure 2 presents the same simulation results using express (2-day) air transportation.

6 CONCLUSIONS AND RECOMMENDATIONS

6.1 Conclusions

- The consolidation of the Argentine Air Force and the Brazilian Navy aviation electronic component inventories will benefit both Armed Forces in higher fleet operational availability. It provides an average increase of 0.678 aircraft over a period of ten years for Argentina, and an additional 0.973 aircraft for Brazilians. Reducing transportation time by changing from sea transportation mode to air mode will also increase the fleet operational availability by approximately 6%. This represents having an additional 3.5 aircraft without increasing the spare parts.
- The concept of fast repair cycle time was highlighted by observing that using a rapid and responsive shipping mode, such as air mode, will reduce the volume of spare items required in the system inventory to achieve a specific A_0. Although the air transportation cost for an LRU/SRU is more expensive than the sea transportation cost, this additional expense is by far offset by having additional availability of aircraft for higher military readiness.

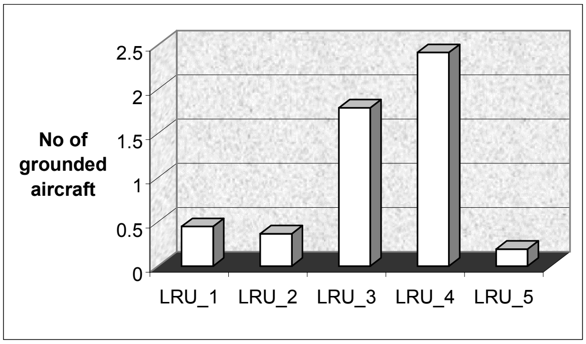

Figure 1: Average Number of Grounded Aircraft due to Particular LRU Using Sea Transportation

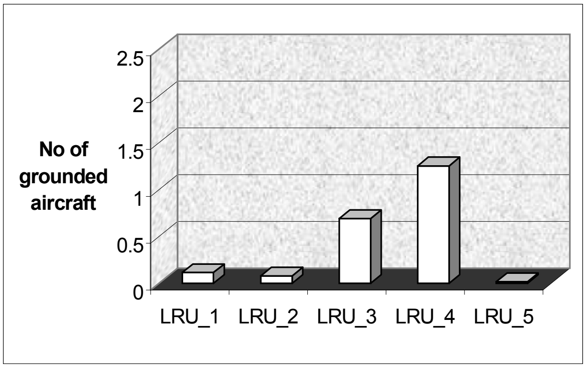

Figure 2: Average Number of Grounded Aircraft due to Particular LRU Using Air Transportation

6.2 Recommendations

The lessons learned our analyses suggest:

- Taking advantage of the political times that Brazil and Argentina are enjoying in terms of an integration process, a collaborative inventory management of their A-4 fleet should be analyzed and implemented. This will bring economical and operational advantages to both Argentina and Brazil.
- We strongly recommend the reduction in transportation cycle time by changing from sea mode to air mode as the way of shipping aviation electronic components to manufacturers in the United States for D-level maintenance.
- Critical components must be closely tracked and have their related data accurately recorded. Historical data collection of Mean Time Between Failures, Mean Time To Repair and so on, is important. We encountered a lack of information during our data collection process from the Argentine Air Force and the Brazilian Navy. Different explanations were given such as information was unavailable at the time of the A-4 aircraft acquisition, lack of resources, poor managerial tools and organizational cultural reasons.
- We suggest further studies to analyze the implementation of total asset visibility between the Brazilian Navy and the Argentine Air Force inventory systems, and the possibilities to standardize critical components for both the A-4 aircraft fleet to make the inventory consolidation more effective.
- Advantages of joint contracting policies for acquisition, repairing, and shipping of aircraft components are recommended for future research.

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