HIERARCHICAL MAINTENANCE STRUCTURE CHANGE FROM 3-LEVEL TO 2-LEVEL MAINTENANCE…IS IT BENEFICIAL?

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ABSTRACT

The United States Air Force (USAF) is under constant pressure to down size and increase efficiency due to congressional mandates and budget cuts. Moving from three-level to two-level maintenance is one method used by the USAF to downsize and reduce overhead costs. This research examines the effect of maintenance resource collaboration and a centralized repair facility on a critical line replacement unit for a major USAF weapon system. Maintenance data is collected, summarized into probability distributions and used in a discrete event simulation model to examine the impact of changes to the Air Force hierarchical maintenance structure.

INTRODUCTION

B-1 bombers are a mainstay of the USAF bomber fleet. Significant resources are used to ensure aircraft availability. The B-1 Bomber avionics repair process is the focus of this study, in particular the AN/ALQ-161 Defensive Avionics System electronic components. Simulation and modeling is used to predict the effects of different maintenance organizational structures for repair processes to the AN/ALQ-161. The effectiveness of repair operations is measured by machine utilization and work in process (WIP) time. This research investigates the effects of resource collaborations among units and centralized repair on parts availability for the B-1 Bomber weapon system.

The AN/ALQ-161 Electronic Counter Measure (ECM) system is the specific focus of this research. It consists of roughly 33 line replaceable units (LRUs) and over 900 shop-replaceable-units (SRUs). The overall maintenance model for aircraft repair involves a hierarchical system of main and sub-components. Main components, the LRUs, are removed from aircraft as required. This rapid removal allows the technician to quickly troubleshoot and isolate faulty components. Furthermore, this LRU modularity permits the technician to replace the LRU immediately should the repair take longer than anticipated. Each LRU consists of multiple SRUs. These SRUs are replaced as needed to repair the LRU. Effective and efficient maintenance requires a balance between on-hand SRU inventory and the cost of that inventory. Currently, the average organic (base-level) LRU repair capability of the AN/ALQ-161 is approximately 80%, which means the remaining 20% of LRU repairs must be accomplished through other resources (either sent to a depot facility or to a contractor). Due to the USAF's hierarchical maintenance system architecture, LRU repair capability is only as good as the availability of SRUs on-hand. For this study, we assume sufficient inventories of SRUs to facilitate LRU repair and isolate our investigation on LRUs for the AN/ALQ-161.

The explicit purpose of this research is to understand and describe any effect of maintenance resource collaboration and a centralized repair facility on the current AN/ALQ-161 LRU maintenance processes and, in turn, the B1-B aircraft availability. The identification of the potential effects of these system enhancements is made possible through the utilization of computer modeling and discrete event simulation.

BACKGROUND

The USAF must provide highly efficient and skilled maintenance for its aerospace weapon systems, such as the B1-B to sustain air superiority. Maintenance tasks are either preventive or corrective in nature and are divided into two categories: on-equipment and off-equipment. On-equipment is the process in which the maintenance task is performed directly on the aircraft, while off-equipment maintenance is carried out on a removed component [1]. Most Air Force weapon systems are currently repaired at three different levels [1]: organizational (on-equipment), intermediate (off-equipment), and depot. This is referred to as three-level maintenance (3LM). In 1998, the USAF, where applicable, mandated a shift towards a two-level maintenance (2LM) concept. In the 2LM system, the intermediate (off-equipment) repair is removed from the process to reduce unit-level maintenance manning requirements and unit-level maintenance costs. The advantages of this particular approach are achieved by leveraging state-of-the-art communications, item visibility, and fast transportation systems. These advantages make it possible for any unserviceable parts to move rapidly to a regional depot or contractor repair process. A regional repair center is a hybrid of 3LM and 2LM systems and combines intermediate level maintenance from multiple bases into one location [1]. This hybrid approach is known as a Centralized Intermediate Repair Facility (CIRF) and is designed to handle all intermediate repairs while allowing the depot to perform the same type repair it does under the traditional 3LM system.

Related Logistics Research in Modeling and Simulation

Many examples exist of successful simulation modeling of both intermediate and depot level maintenance. Shyong [5] evaluated the effects of various spare parts levels and queuing policies on process time and cost for the overhaul of the F101 Low Pressure Turbine (LPT) rotor at Tinker Air Force Base (AFB). Another example of simulation modeling can be seen in Rodrigues and Karpowicz [4], as they analyzed the impact of reducing transportation cycle times and consolidating inventories on the operational availability of the Brazilian Navy and Argentine Air Force A-4 fleets. ARENA software was used to build their model and proved beneficial in establishing the necessary requirements and structure for analysis. Vigus [6] used discrete event simulation to assess the impact of process changes to various Programmed Depot Maintenance (PDM) lines for the Coast Guard's HH-60J search and rescue helicopter. The similarity of independent variables and repair system logic provide a solid foundation for model creation and research of the AN/ALQ-161 LRU repair processes.

METHODOLOGY

The AN/ALQ-161 maintenance process involves a fairly complex repair network. LRUs removed from the aircraft are sent to the "back-shop", or intermediate repair facility, for troubleshooting and possible repair. Some LRUs are sent to certain automated test evaluation (ATE) stations where set-up, tear-down, and process times vary dramatically. For this effort, ATE maintenance procedures were assumed homogeneous for all LRUs. Once a LRU is deemed repairable, it proceeds through either one or two ATE stations, depending on LRU type; they are processed and sent to an appropriate repair station. The final step is the return of the LRU to its original inspection station for a final quality assurance test. LRUs have the potential to fail at any stage in the intermediate repair cycle; at that point, they are declared not-repairable-this-station (NRTS) and are sent to depot for repair.

Data collected from this repair process was analyzed for probability modeling. All the data and information used for this study were received from the B-1 Electronic Warfare Systems Manager (ACC/A4F1). The data provided average repair times and service rates for the number of LRUs produced by each base. LRU arrival rates were based on the number of LRUs per base. Repair averages, with levels at plus and minus 15%, were used in a triangular probability distribution to model repair times. ATE resources were limited, while maintenance personnel were assumed always available for any repair.

Three models were created and used to conduct the analyses. The first model approximates current LRU repair operations at Dyess and Ellsworth AFBs, with no collaboration or resource sharing between the two bases. This repair independence approximates the current AN/ALQ-161 LRU repair process and provides baseline results for subsequent analyses. The second model mimics intermediate repair collaboration between the bases, capturing a hybrid-CIRF process. An example of this would involve a LRU that arrives for inspection at a base but transfers to the other base if the present repair queue is too long; in queuing this behavior is known as “jockeying.” Notional transportation times were used for any transfer, however, this study did not include the associated cost. The third model developed completely removed the base intermediate repair capability out of the process and set up a full CIRF to complete the LRU repair. All three models were animated by adapting models from Mousavi [3].

Customer entities, failed LRUs in this case, are generated using a Poisson Process based on each base’s LRU failure rate. Once created the LRU entity routes to a station and is prepared for its initial inspection. ATE sequencing is not mandatory thus an entity requiring both inspections starts at either ATE. However, LRUs requiring both inspections defaulted to the Defensive Avionics Augmentation Equipment (DAAE) inspection first, while the others are directed to the Radar/Electronic Warfare (R/EW) process. Entity routing mimicked the real-world by using a time delay associated with the removal and transportation of the LRU to a back-shop for repair. All delays used in the model are assumed to be uniformly distributed and are based on expert opinion in such maintenance operations.

Once a LRU is routed to the appropriate ATE station, a decision module is used to discriminate among LRUs repairable at this station. The probability of repair for each LRU was extracted from the original data based on average annual service rate. A failed LRU is considered NRTS, and is routed to the depot for repair. Conversely, a LRU passing inspection is sent to its predetermined ATE station. All repair and inspection times are modeled using a triangular distribution, which are known to provide adequate behavior when distributional aspects of such behaviors are unknown or uncertain.

The predetermined ATE for each base’s LRUs is identical. Each LRU proceeds from its routing station to its required ATE station. There are two inspection stations, R/EW and DAAE, and both stations require one operator resource to operate. The LRU attribute ***inspection time***, is used for that particular LRU. The repair lines for both bases are identical. The R/EW ATE model logic is straight forward; LRUs arrive at the inspection station and inspected according to the ***repair time*** assigned. Immediately, a decision module assesses a probability of repair success. There is a 95% chance of a successful repair. A successful initial repair routes the LRU back for an expedited final inspection before its return to its appropriate base supply.

LRUs requiring two inspection stations can jockey. This means, for example, an entity arriving to the DAAE inspection station looks at the number in that queue and compares it to the number in the queue of the R/EW. If the DAAE queue size is greater than one, and the R/EW queue is open, the LRU will jockey to the other queue. Both queue length values are notional and were set to facilitate future customization and add an element of common-sense maintenance processes through efficient resource utilization. A LRU that successfully proceeds through the DAAE inspection is then routed to the R/EW station as required.

Once a LRU has completed its respective inspection station requirement it proceeds to the back shop. This back shop repair process is similar to the inspection process and is based upon the average LRU ***repair times*** assigned earlier in the model. Notably, new and reduced inspection times are assigned to entities. LRUs return to inspection stations based upon their entity type. LRUs under re-inspection have higher priority than items in the queue and shorter inspection times. Finally, the repaired LRUs return to base supply based upon the new entity type that was assigned after the repair process. Model 2 is very similar in process flow to Model 1, but differs in that system resources are shared.

The third model simulates the full CIRF concept. Within CIRF, all intermediate repair processes, such as inspection and repair, are removed from the base level repair network and transferred to the CIRF. After the repair process for the CIRF, a new entity attribute is assigned along with new and shorter inspection times. As seen in the other two models, the repaired LRU's take precedence in the queue during the re-inspection process.

All three models begin in the **"*empty-and-idle*"** state; no entities created and all resources are idle [2]. A "warm-up" period is used to bring the simulation up to normal operating conditions. However, determining the warm-up period is not a exact science. Kelton et al. [2] recommends using one of two different techniques. The first technique is to establish a single overall output performance measure (such as WIP) and monitor its output during simulation runs. Eventually, there is a period when the measure reaches a steady state. A process is in steady state when its measure of performance, such as average WIP, has settled down to some value (usually close to its long-term expected value). This steady state point defines the initial warm-up period. The second technique runs the model for such a long period of time that any potential bias caused by the warm-up period is overwhelmed by the amount of later data [2]. For all three models, a warm-up period of 5 days was used with all data from the warm-up period deleted from the overall measurement calculations.

A total of 20 different scenarios were used to analyze three maintenance structures. ARENA's Process Analyzer Tool was employed to quickly modify the resources within each computer experiment, run the experiment, collect the data, and compare the results. In all three models, the baseline is the initial condition where all resources (R/EW, DAAE and repair stations) are set to a level of one. Different combinations of resources define each unique scenario. Each iteration produced results that are compared against the baseline to determine levels of significance. The best scenario for each model was then selected.

RESULTS AND ANALYSIS

The experiment involves a hypothesis designed to examine what maintenance configuration may contribute to an overall improvement in machine utilization and WIP. Given outputs from simulations of the two alternatives, the hypothesis is:

$$H_o: P_1 - P_2 = 0$$

$$H_a: P_1 - P_2 \neq 0$$

Where: P_1 = total average WIP for scenario 1, and P_2 = total average WIP time scenario 2. The null hypothesis, Ho, assumes no difference exhibited in WIP times between scenario 1 and scenario 2. If the test rejects the null hypothesis, there is a significant difference in WIP times and the alternate hypothesis is accepted. However, if the hypothesis test fails to reject the null, no conclusion regarding the alternate can be made [6].

A paired t-test was accomplished due to unequal variances of all scenarios output. This test produces confidence intervals for the difference of means. The test fails to reject the null hypothesis when the confidence interval "hooks zero" [6]. As a requirement for the paired t-test, equal sample sizes were used for all three models.

Additionally, the null hypothesis was rejected when a confidence interval exists that does not contain 0, which supports the conclusion that the differences in mean outputs are statistically significant between scenarios 1 and 2.

Machine Utilization

Machine utilization for each scenario was calculated using the ARENA's process analyzer. This utility creates scenarios by changing resource levels and giving model output for comparison. The best results for Models 1 and 2 were apparent when two repair stations were added to both Ellsworth AFB and Dyess AFB. The CIRF scenario resulted in increased repair equipment utilization. It should be noted adding two repair stations to the CIRF (Model 3) gave a comparable result to Model 1 and 2, for half the resources required. Models 1 and 2 required addition of two repair stations to each location.

Work In Process

ARENA's output and process analyzer utilities were used to test for significance between each scenario. In all 20 scenarios, an individual confidence interval of 95% was used in the selection of the best case scenario. Finally, total WIP was calculated from the simulation statistic function in ARENA, producing the results for the three models by scenario. The largest return on investment for all three models was evident when resources were added to the repair station. For Models 1 and 2, adding resources to the Ellsworth AFB repair station had the greatest benefit from an enterprise viewpoint reducing WIP by nearly 36 units. However, the CIRF concept, Model 3, reduced WIP by nearly 60 units for Ellsworth AFB and 46 units for Dyess AFB.

VALIDATION

The limited amount of empirical data was a factor, however all three models were created based on actual processes and driven by available real-world data. The triangular distributions are used in order to scope the high level of complexity.

CONCLUSIONS

This research utilized discrete event computer simulation to help predict the impact of different maintenance organizational structures on the AN/ALQ-161 LRU repair process. Machine utilization and WIP are the two measures of effectiveness evaluated in this study.

Resource sharing between Ellsworth AFB and Dyess AFB brought forth both advantages and disadvantages to their respective maintenance processes. The main advantage recognized was leveled machine utilization for both inspection stations at Dyess AFB. Additionally, LRUs were shipped from Ellsworth to Dyess, thus facilitating resource collaboration and helping to more evenly distribute the workload for both bases. However, some of the shortcomings with this approach include; the costs associated with shipping LRUs between bases grows, the management of assets in route increases system complexity, and having multiple process owners tends to increase concerns.

Implementing the Centralized Intermediate Repair Facility (CIRF) for all ALQ-161 LRUs has benefits as well as certain drawbacks. The first benefit is evenly distributed machine utilization. Inspection, and repair stations are efficiently and effectively used since they are at the same location. LRUs are routed to a single location for repair where equipment and manpower are consolidated. Second, replacement SRUs are centrally located which reduces redundancy and the need for management of two separate supply chains. Third, machine utilization is increased as repairs are centrally located. A significant reduction in cost associated with the consolidation of resources and personnel is certainly an advantage of the CIRF process. While cost and manpower were not a focus in this study, it is easy to see that a single process owner and enterprise focus on repair management is advantageous.

The disadvantage to the CIRF concept is the relinquishment of LRU control by the base. Since all LRUs are sent off base to repair, the using organization does not have immediate LRU repair capability. The organization must rely on having spare LRUs in the base supply system. Serviceable LRUs can immediately replace faulty ones, however if the LRU is not available on base there is no capability to repair the LRU at the base level.

The CIRF maintenance concept evenly distributes machine utilization and reduces WIP which increases serviceable LRU availability. Additionally, half the number of resources are required to see substantial results. 2LM does work and with resources reductions it is a viable option to keep the USAF as a premier air power.

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