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ANALYSIS OF ELECTRONICS ASSEMBLY OPERATIONS: LONGBOW HELLFIRE MISSILE POWER SUPPLY

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ABSTRACT

This paper describes the use of discrete event simulation and design of experiments to analyze and improve electronics assembly operations. A study was performed to determine if proposed changes to electronics assembly operations could achieve higher production throughput. This work supported the U.S. Army's Longbow HELLFIRE Missile program. The design of experiment used a modified orthogonal array containing both two and three-level factors. The authors describe the use of factor level average analysis to analyze experimental data. The Army used study results to assess risks in the program while the manufacturer gained information needed to improve the efficiency of its operations.

1 INTRODUCTION

The AH-64 Apache is the premier helicopter used by the U.S. Army to defeat enemy mechanized forces. The HELLFIRE missile is the primary weapon used by the Apache in this role. An upgrade currently under development is designated the AH-64D, Longbow Apache. This upgrade will improve the performance, survivability, and reliability of the Apache helicopter. Enhancements include a fire-and-forget weapon system, multiple target engagements, and exchange of targeting data with other combat elements. An upgraded missile, the Longbow HELLFIRE Modular Missile (LBHMM), is an integral part of the AH-64D weapon system. A new seeker with an active radar gives the Longbow HELLFIRE Missile a fire-and-forget engagement capability.

The Longbow HELLFIRE Missile is produced by a joint venture of Lockheed Martin Corporation and Northrop Grumman Corporation. Northrop Grumman produces the Guidance Section (GS) for the missile. The Power Supply (PS) is a major component of the Guidance Section and the subject of this study. Figure 1 depicts the Longbow HELLFIRE Missile.

The Longbow HELLFIRE Missile program will transition from Low Rate Initial Production (LRIP) to Full Rate Production (FRP). Northrop Grumman will implement planned changes to the GS manufacturing system to achieve the substantially higher production volume required in FRP. Both the Army and Northrop Grumman were interested in analyzing selected components of the GS manufacturing system to determine if the proposed changes can achieve the higher production volumes. One area of interest was the PS assembly operations.

The Army commissioned a study of the PS assembly operations. Discrete event simulation was the primary tool used to estimate PS throughput and other manufacturing characteristics at two Northrop Grumman facilities – one facility in College Station, Texas, and another in Huntsville, Alabama. This study provided information that the Army needed to make a risk assessment of the Longbow HELLFIRE Missile program as it transitions to FRP. It also provided information that Northrop Grumman used to refine its proposed changes to the PS system to improve efficiencies related to resource utilization and control of work-in-process (WIP). See Springfield and Hall (1998).

Subsequent to the initial study of the PS assembly operations, Northrop Grumman proposed major changes that would move selected PS operations from their Texas facility to the Alabama facility. This paper describes the additional simulation analysis employed in the follow-on study used to analyze these proposed changes for the Huntsville, Alabama, facility.

2 MANUFACTURING SYSTEM OVERVIEW

The new PS assembly operations proposed for the Alabama facility includes several assembly and testing operations. At this facility, Northrop Grumman will receive a partially assembled PS circuit card assembly (CCA) from the Texas facility and build it into a completed

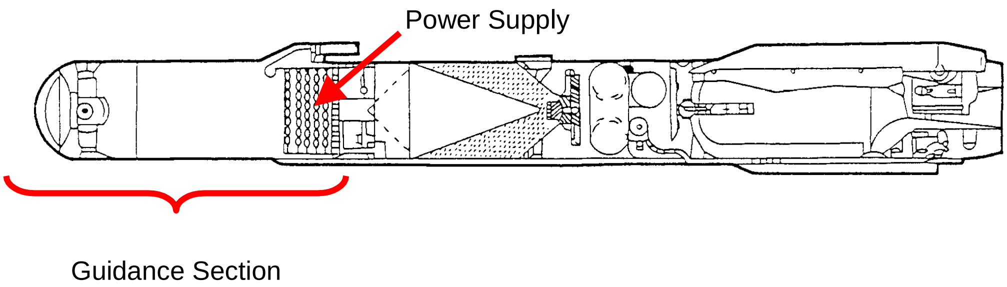

Figure 1: Longbow HELLFIRE Missile

CCA. A CCA is the lower level component of the final PS. Northrop Grumman will then build the CCA into an electronic circuit assembly (ECA). The completed ECA is the end product Power Supply.

Operations needed to complete the Power Supply CCA include the attachment of cable harness assemblies and other components, conformal coating by a subcontractor, circuit testing, and inspection. Assembly operators perform most of these operations on the CCA. Test operators build the CCA into a ECAs and conduct testing. The testing includes a bench test (circuit testing), vibration test, environmental stress screening (ESS) test, and a final bench test. Test operators then affix a final component and weigh each PS before an inspector performs a final inspection. Figure 2 depicts the PS assembly, testing, and inspection operations proposed for the Alabama facility. This figure also depicts the major resources addressed in this study.

3 MODEL DEVELOPMENT

The proposed PS operations were modeled using the ARENA™ simulation software. Operations at the Alabama facility begin with the arrival of partially assembled Power Supply CCAs. Receiving operations were represented in the model by a series of advanced servers. A batch statement was used in conjunction with the advanced servers to limit the number of kits to be loaded on a cart for movement to the assembly area.

Assembly operators working in parallel complete the CCA build. Each assembly operator retrieves a kit from a storage area and performs required assembly operations at their workstation. As an intermediate step, CCAs are sent to a subcontractor for conformal coating. An inspector

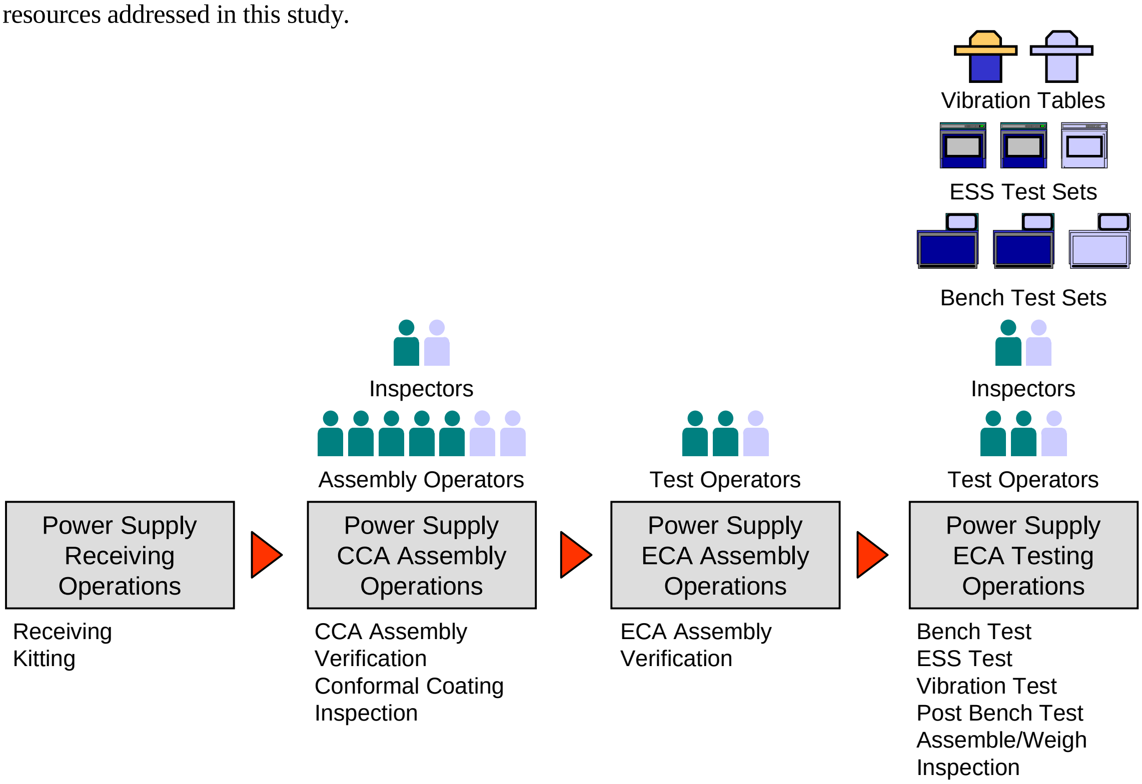

Figure 2: Power Supply Operations and Resources

reports to the assembly area to inspect completed CCAs. In the ARENA model, a CCA is routed from a single station (queue) to an advanced server that represents an assembly operator. Since the operators retrieve the kits, the number of kits being routed to the assemblers had to be limited. This was accomplished by a scan block checking for a condition in which the number of kits routing to the assemblers, in queue for the assemblers, and the number being processed by the assemblers was less than the total number of assembly operators. When this condition was met, a kit was released to the assembly area and assigned to an idle assembly operator.

Test operators perform assembly and test operations in the test area. A test operator builds the CCA into a completed Power Supply ECA. A test operator then moves each ECA through a sequence of tests that include a bench test for circuit integrity, a vibration test, a temperature-cycling ESS test, and a post bench test to recheck circuit integrity. Should an ECA fail a test, the test operator performs troubleshooting to determine if it should be reworked by an assembly operator or returned to the Texas facility for rework. The final tasks performed by the test operator are the installation of a structural part and weighing the PS. The test operator then moves the Power Supply ECAs to a storage area to wait for final inspection. The test operator is modeled using a guided transporter. This transporter follows a sequence corresponding to the assembly and test operations. For assembly and test operations requiring the test operator, the test operator transporter was requested and delayed for the required processing time before being freed. The vibration and ESS tests are automated and only require the transporter for loading and unloading the ECAs to and from the test equipment. Both the vibration and ESS tests have capacities greater than one and are allowed to accumulate the required number of ECAs before processing.

Final inspection is the last operation performed in the ECA testing area. An inspector reports to the area, retrieves a completed Power Supply from storage, and moves it to an inspection bench. After passing inspection, the PS is placed in a kit for assembly in the missile's Guidance Section. The inspector was modeled with the use of a free path transporter that moves ECAs from the storage area to the inspection station. After final inspection, the PS entities depart the model.

4 EXPERIMENTATION AND ANALYSIS

Experimentation and analysis of the proposed manufacturing system was conducted in two phases. Phase 1 analysis sought to determine operating characteristics of the PS assembly operations as proposed by the Northrop Grumman engineers and addressed in a facility layout study. Results of the Phase 1 analysis suggested that while the system could meet required production volumes (throughput), utilization rates for the assembly operators were at unacceptably high levels. Phase 2 analysis sought to identify changes needed to address the utilization rates of the assembly operators and determine if other system design parameters could be changed to make the system more efficient. This section describes the Phase 2 experimentation and analysis.

4.1 Design of Experiment

The objective of this experiment was to determine the optimal number of operators and items of test equipment needed to satisfy the FRP Power Supply delivery rate. Not only was the high utilization rate of the assembly operators of concern, but Northrop Grumman also wanted to examine staffing levels of test operators and inspectors. Northrop Grumman also planned to procure additional items of test equipment. This experiment examined the need for this additional testing capacity.

Figure 3 presents the response variables, control factors, and levels considered in this experiment. Seven response variables addressed PS throughput and the utilization rates of selected operators and items of test equipment.

Six control factors addressed the number of selected operators and items of test equipment in the PS system. The test equipment – ESS chambers and test sets (Factor

Response Variables (y)			
y_1 = throughput (units/month)	y_5 = utilization rate vibration test		
y_2 = utilization rate assembly operators	y_6 = utilization rate ESS test		
y_3 = utilization rate test operators)	y_7 = utilization rate bench test		
y_4 = utilization rate inspectors			
Control Factors	**Level 1**	**Level 2**	**Level 3**
A Number of ESS chambers & test sets	2	3	
B Number of vibration tables & test sets	1	2	
C Number of bench test sets	2	3	
D Number of assembly operators (1st shift only)	5	6	7
E Number of test operators (1st shift/2nd shift)	2/1	2/0	1/1
F Number of inspectors (1st shift only)	1	2	

Figure 3: Response Variables, Control Factors, and Levels

A), vibration tables and test sets (Factor B), and bench tests sets (Factor C) – were each examined at two levels. Level 1 for test equipment corresponded to the number of units currently fielded on the shop floor and Level 2 corresponded to the number of items that Northrop Grumman planned to add to the PS system. The assembly operators (Factor D) and test operators (Factor E) were examined at three levels. Level 1 represents the number of operators currently supporting LRIP operations. Since the utilization of assembly operators proved to be high in Phase 1 analysis, Levels 2 and 3 examine additional operators. Since Phase 1 analysis suggested a lower than expected utilization rate for test operators, Levels 2 and 3 examine one fewer operator for either the first or second shift. The inspector (Factor F) was examined at two levels. Level 1 represents the current number of operators while Level 2 is an increase of one.

To accommodate the four two-level factors at two three-level factors, a modified L_{16} orthogonal array (OA) was used as the experimental design. Figure 4 presents this OA. A standard L_{16} OA was modified as suggested by Peace (1993) using column building to create two four-level columns from selected two-level columns. Since only three levels are needed for Factors D and E, a dummy factor level was used in lieu of the fourth level. The factor level chosen for the dummy level was one that the authors considered as needing the most additional information. For this problem, Level 2 was chosen as the dummy factor level for both Factors D and E. In Figure 4, the prime sign (e.g., 2′) denotes these dummy factor levels.

	Control Factors					
Trial	A	B	C	F	D	E
1	1	1	1	1	1	1
2	1	1	1	1	2	2
3	1	1	1	2	3	3
4	1	1	1	2	2′	2′
5	1	2	2	1	3	2′
6	1	2	2	1	2′	3
7	1	2	2	2	1	2
8	1	2	2	2	2	1
9	2	1	2	1	3	1
10	2	1	2	1	2′	2
11	2	1	2	2	1	3
12	2	1	2	2	2	2′
13	2	2	1	1	1	2′
14	2	2	1	1	2	3
15	2	2	1	2	3	2
16	2	2	1	2	2′	1

Figure 4: Design of Experiment–Modified L_{16} Orthogonal Array Analysis

Five replications of the simulation were run for each trial. To ensure the model reached steady state, each trial used a 6 month warm-up period followed by a 12 month period for data recording.

4.2 Analysis

The authors used factor level averaging to analyze the experimental results as described by Peace (1993). Response tables and graphs were constructed for each response variable. These tools allow the analyst to determine the factor levels that have the strongest effect on the response variable. Acceptable PS system parameter settings were judged as those that achieved FRP throughput requirements while maintaining utilization rates of operators and test equipment below 80%.

Figure 5 presents a response graph for bench test utilization (response variable y_7). This graph suggests that the number of test operators (Factor E) has a strong effect on bench test utilization. The large change in the value of utilization from its lowest when Factor E is set at Level 1 to its highest when Factor E is set at Level 3 indicates the strong effect of this factor. The number of bench test sets (Factor C) and the number of assembly operators (Factor D) are weak factors with respect to bench test utilization. The changes in utilization over the levels of these factors are apparent; however, they are much smaller than for Factor E. The remaining factors are considered to have no significant effect on the response variable.

Analysis sought to determine solutions requiring the minimal amount of resources (operators and test equipment) needed to achieve the FRP requirements. It is noteworthy that the PS system was robust with respect to unit throughput at the FRP production rate for all factors and levels. Recommendations for system modifications were driven not by a concern for achieving required throughput, but for resource utilization. The addition of one assembly operator solved the utilization problem found earlier. Ample capacity was available using the test equipment currently on the shop floor; therefore, the authors recommended that Northrop Grumman not procure additional test equipment.

A confirmation test was run using these recommendations. Thirty replications of the simulation were run for this experiment at the approximate FRP rate. For each replication, the simulation used a 6 month warm-up period followed by a 12 month period for data recording. Results confirmed that FRP throughput can be achieved with the addition of one assembly operator and without additional test equipment.

5 CONCLUSIONS

Simulation proved to be an effective tool to analyze projected changes in a defense production system. Simulation provided the Army with information needed to

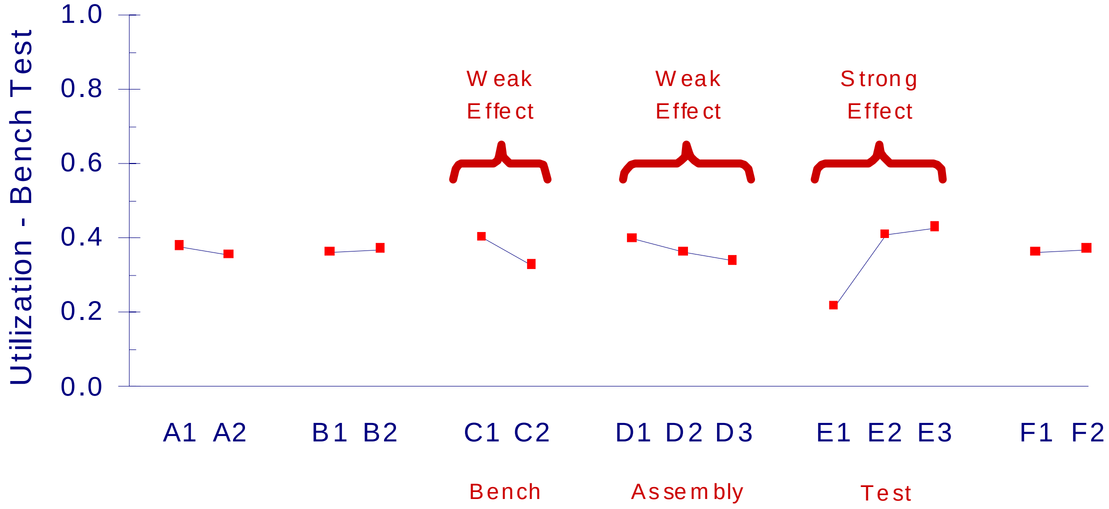

Figure 5: Sample Level Average Analysis Response Graph: Bench Test Utilization

make an assessment of programs risks associated with the Longbow HELLFIRE Missile. Because simulation suggested that the Power Supply assembly system is capable of meeting FRP requirements, the Army assessed this as a low schedule risk.

Simulation also provided a means for Northrop Grumman to analyze proposed changes to the PS production system. This study demonstrated that an additional assembly operator would cause a reduction in utilization rate of this resource to an acceptable level.

Other improvements suggested in this study focused on improving the efficiency of the proposed PS system. Analysis suggests that the FRP rate can be achieved without procuring additional test equipment. This recommendation considered only throughput and resource utilization. While other factors will impact Northrop Grumman's decision to field this equipment, its management now has evidence that suggests that some of this equipment costs could be avoided.

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