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ReARMM Modification Planner

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Abstract: Project Management Office for Aircraft Survivability Equipment (PM ASE) plans and coordinates all aircraft modifications for the United States Army. Scheduling maintenance on rotary-wing aircraft is extraordinarily complex, with many factors to consider throughout the process. Fort Hood and Fort Campbell are the ReARMM Modification Centers (RMCs), where PM ASE is currently supporting the Regionally Aligned Readiness & Modernization Model (ReARMM) to to schedule aircraft modification. The purpose of building the ReARMM Modification Planner is to allow PM ASE to calculate an optimized modification schedule for different variations of aircraft modification packages by altering the number and type of aircraft, amount of available hangar space, and other variables. Each of the modification packages is made up of several Modification Work Orders (MWO). Upon completion, the ReARMM Modification Planner will be implemented immediately by PM ASE as this tool is crucial for optimizing aircraft modification schedules for the United States Army.

Keywords: PM ASE, ReARMM, RMC

1. Background

Aviation is one of the most crucial assets to the United States Army. Before aviation units can deploy or engage in deployment preparation training such as National Training Center (NTC) and Joint-Readiness Training Center (JRTC), multiple survivability packages and modifications are installed on each aircraft. The current problem regarding aircraft modification is that modifications often take long periods to complete. The longer it takes for an aircraft to be modified results in longer wait times until soldiers may resume training on that aircraft. It is very difficult for soldiers to uphold unit readiness without the ability to train with the aircraft; therefore, it is essential to develop a tool that will help plan and regulate aviation maintenance and modification as efficiently as possible to reduce the total amount of time that aircraft are out of operation. The airframes which require survivability modifications consist of UH-60V, UH-60L, UH-60M, AH-64E, AH-64D, CH-47 1, CH-47 2, and HH-60M.

1.1 Literature Review

Optimization, with regards to aircraft fleets, is tremendously critical. This is because aircraft optimization can be a complex and fluid problem that requires multiple inputs. Aircraft fleet readiness has substantial implications in both the civilian and military realms. In the civilian realm, maintenance optimization can decrease the total cost of operation and therefore increase a firm's profit. In the military sector, being able to accurately plan and complete aircraft maintenance has a substantial effect on the force. Due to the modernization of the United States Military, aircraft have become a significant factor in training and deploying a combat force. Due to this importance, along with being a publicly funded organization, optimizing the maintenance and upkeep of a fleet demands both interest and study.

Mattila and Virtanen created a model to schedule maintenance for a fleet of fighter aircraft. To do this, they created a model that utilizes multi-objective simulation optimization. Their goal was to minimize the time between a targeted maintenance start time and actual start time while increasing the overall aircraft availability of the fleet. The problem is complex due to the requirement of aircraft to receive maintenance after a specific amount of flight hours and because certain aircraft may be needed at certain times to complete missions. The model also must consider what resources are available and when said resources are available. (Mattila & Virtanen, 2014). After finding non-dominated solutions, the model applies a value function to each. This gives the decision-maker recommendations for how each solution can meet the needs and accomplish the goal of an organization. To increase ease of use, the decision-maker inputs their preferences after possible solutions are found. This increases the flexibility of the model as a decision-maker can change preferences and see the results without the drawbacks of preferences being tied to an objective function. This tool is, therefore, extremely helpful in allowing a decision-maker to fully look through and process the merits of candidate solutions and make a good decision.

Sohn and Yoon also looked at scheduling for military aircraft. They specifically looked at non-constant and varied mean time to failure and mean time to repair of aircraft. This leads to a more informed and optimal way of conducting preventative maintenance. To accomplish this, the researchers used a “random effects Weibull regression model” (Sohn & Yoon, 2010). In using a Weibull probability distribution, the researchers were able to account for varying real-life instances. Sohn and Yoon found that their model had “several advantages over the constant schedule policy” (Sohn & Yoon, 2010). However, they acknowledged that the non-constant and complex nature of their outputs may be too difficult to fully implement.

Semaan and Yehia created a model for scheduling military rotorcraft. They used stochastic modeling to better replicate the real world. (Semaan & Yehia, 2019). The researchers attributed different probability distributions to each maintenance task to better replicate how long a repair or task might take. They were able to estimate a distribution that shows how long a maintenance check may take. This is immensely helpful with scheduling. By adding a stochastic element, decision-makers are better able to judge the likelihood of how long maintenance will take. This is beneficial over discrete estimation as a repair may have a large or small variation in time. Being able to assess the variation enables the model to better represent reality.

1.2 Problem Statement

The purpose of this project is to develop a ReARMM Modification Planner used to schedule maintenance and modifications on United States Army aircraft. The ReARMM Modification Planner will use input provided by users to determine an optimal solution identifies the amount of time it will take to modify a specific number of aircraft. Figure 1 depicts each stage of the ReARMM modification process from start to finish. This tool will be incredibly helpful to the United States Army as it will minimize the number of aircraft out of operation at a given time, while still allowing for aviation training within units.

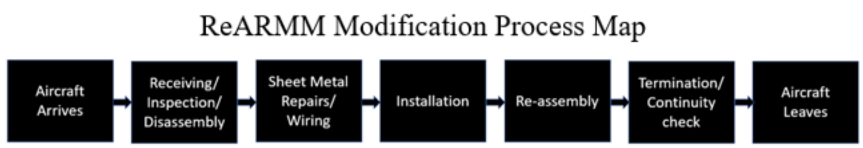

Figure 1. Outline of ReARMM Modification Process

2. Methodology

2.1 Stakeholder Analysis

To ensure the ReARMM Modification Planner meets the needs and wants of the Army and the ReARMM program, stakeholder feedback was integral. The team met with PM ASE and Program Executive Office (PEO) Aviation frequently, as they were the client and primary coordinators of the work on the ReARMM Modification Planner. In an agile approach to stakeholder analysis and model development, the team decided to meet with the stakeholder every two weeks to provide updates to PM ASE and get feedback. Following each meeting, the team would implement any changes within the planner and ensure proper functioning before the next meeting. The benefit of meeting multiple times throughout the process was that there was little to no room for misinterpretation leading to building a model outside their scope. If there was ever confusion or misinterpretation by the team or either of the stakeholders, it was quickly addressed and corrected in the next meeting.

Finally, it is crucial to understand that the Soldier population in the Army is a key stakeholder in this project by ensuring that the ReARMM Modification Planner works properly and efficiently will allow the Soldier population in the Army to be better equipped to be combat-ready. The more specific and accurate the planner is, the easier it is to keep track of when aircraft are ready to fight.

2.2 General Assumptions, Constraints, and Limitations

To make the model in Excel, multiple assumptions must be made. Many of the assumptions have to do with the workers in the Excel model. Due to the limitations of Excel, every worker is assumed to be equal in capabilities. This directly impacts the assumption made on how long an individual aircraft takes to undergo modification. Given that all workers have

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the exact same capabilities, the total man-hours it takes to conduct modifications equates to the total man-hours needed, divided by the number of workers. There are no specialized workers such as electricians. Another key assumption for the model is that two non-CH-47 aircraft can fit in one large bay. This assumption is made based on stakeholder information gathered from the team's visit to Redstone Arsenal.

Another limitation of using Excel to model the ReARMM modification process is that the platform Excel used, without add-ons, models the manhours and time needed to modify an aircraft as a discrete variable. This is a limitation as it does not as accurately depict the real world. A stochastic model would be able to show the distribution and mean times to give a user more information and a more complete depiction of the data. To counteract this, the model has an input for a confidence interval which allows a user to account for variability in the real world.

2.3 Optimization

2.3.1 Excel Model

The model uses Excel Solver. Due to time constraints and working on the optimization problem on different programs, one of the main obstacles to creating a complete optimization model was implementing CH47s and the larger bays into the optimization. Because these bays deal with different aircraft and hangars, it posed an interesting problem for the team to implement into the Solver function. The developers ultimately had to alter the model to accommodate the separate bays. First, the decision variable was expanded to show the matrix of smaller aircraft in small hangars as well as their larger counterparts. The team then built constraints similar to the constraints in the original model for larger aircraft. Finally, to create a new objective function, the team took into account larger helicopters in how the model decides the overall iteration time. This led solver to change when CH47s occupied bays to find the most optimal solution possible. Second, stakeholders indicated that there are variations of each aircraft that each has different MWOs that must be accounted for. To do this the team added extra rows to the decision variables to account for the increased number of airframes accounted for.

2.3.2 Mathematical Optimization Model

The ReARMM Modification Planner is modeled in Excel Solver using an optimization with decision variables, objective functions, and constraints. Understanding these input cells and functions allows for an understanding of how the model optimizes and creates an estimation of the total time needed to modify the input aircraft. The decision variable is the variable that Excel modifies to reach a specified goal or value. In this model, the decision variable is a matrix $x_{a,i}$. This matrix is composed of rows indexed on aircraft (a) and columns indexed on iterations (i). This matrix shows how many of each aircraft occupy a hangar during a given iteration. If there is a positive number of a given airframe occupying a hangar during the iteration, the man-hours need to modify one aircraft becomes a potential iteration length ($l_{a,i}$). The objective function derives an optimized solution by minimizing the sum of the iteration lengths: the maximum of the potential iteration lengths per iteration. The iteration length is then computed as being the maximum of the potential lengths. The decision variable can only contain 25 columns of iteration lengths, as the Excel solver is limited to 200 cells within the decision variable. Therefore, based on the potential iterations the objective function for this model is:

$$Minimize \sum_{i=1}^{25} max(l_{a,i}) \tag{1}$$

The constraints for this model are based on modifying the correct number of aircraft based on what airframe they are and limiting the number of aircraft per iteration based on the number of available hangers. The first constraint is that all $x_{a,i} \geq 0$ and are integers. Next, the sum of $x_{a,i}$ for all a's across the iterations must equal the requirement per aircraft (r_a). Therefore, the constraint is written mathematically as:

$$for\ all\ a\ in\ aircraft: \sum_{i=1}^{25} x_{a,i} = r_a \tag{2}$$

Next, the number of aircraft completed during an iteration must be less than or equal to the hangar space available. This constrains the total number of aircraft that can be completed within a given iteration. Therefore, the sum of CH47 helicopters (*c*) must be less than the number of big bays (*b*) during each iteration.

$$for\ all\ i\ in\ iterations: \sum_{c=1}^{2} x_{c,i} \leq b \tag{3}$$

Smaller bays for nonCH47 bays (*n*) follow a similar notation and structure. However, due to our assumptions, the model must account for, two non-CH47 helicopters that are capable of being modified in a single unused CH47 bay (*u*).

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Therefore, the constraint accounts for both the unused CH47 bays as well as smaller bays (s). The model essentially counts an unused large bay as two smaller bays.

$$for\ all\ i\ in\ iterations\colon \sum_{n=1}^{6} x_{n,i} \leq s + 2u \tag{4}$$

The model also has an input for how many HH60s may be modified during a given iteration. This limit is represented as the variable *t*. For each iteration the number of HH60s (x_h) must be less than or equal to the HH60 limit that is imputed by the user.

$$for\ all\ i\ in\ iteration\colon x_{h,i} \leq t \tag{5}$$

2.4 User Interface

During stakeholder analysis, it became clear that the user interface was also an important aspect of the project. The goal of the user interface was to allow a user to input as much data as possible while making the model as simple as possible. The team created an input and output page. This was to separate what a user would input themselves and what the model would produce as an answer and objective value. The model predicts cost based on inputted flight time, burn rates, cost of fuel, maintenance, and the number of aircraft moving to a Center of Excellence. The output page displays the results of the optimization problems and the overall costs. The team developed an Excel macro to simplify running the model. The Excel macro can run multiple models sequentially and then switches the view of the model to the output tab. This allows a user to simply input data, run the model on a separate worksheet without having to click on it, and then view output by running one macro.

To improve the user interface, the team developed additional worksheets that allow a user to select specific MWOs for each aircraft type at each location. When a specific MWO is selected, the total manhours needed to accomplish the modifications are summed together and subsequently linked throughout the model and optimization. This allows a user to select a specific combination of work orders based on aircraft and location. The team also created a parameters page. This worksheet allows a user to change the name of an MWO and the work hours associated with it. This allows a user to input the most up-to-date and relevant data into the model relatively simply. It also gives the calculator a longer useful life as it is more adaptive to changing situations and future aircraft modifications.

Table 1. Inputs and Parameters of 1st Air Combat Aviation Brigade

Location	CoE	Home Station
UH-60V	15	6
UH-60L	5	6
UH-60M	10	6
AH-64E	6	8
AH-64D	6	4
CH-47 1	4	3
CH-47 2	4	1
HH-60M	8	7
Normal Bays Available	3	3
CH-47 Bays Available	3	4

Location	CoE	Home Station
Efficiency Improvement	0.15	0.15
HH-60 Limit	3	3
Workers Per Team	5	5
Confidence Interval (Days)	1	1
Shifts per Day	1	1
Hours per Shift	8	8
Work Hours Per Day	8	8
Work Hours per Day for the Teams	48	40

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3. Analysis and Results

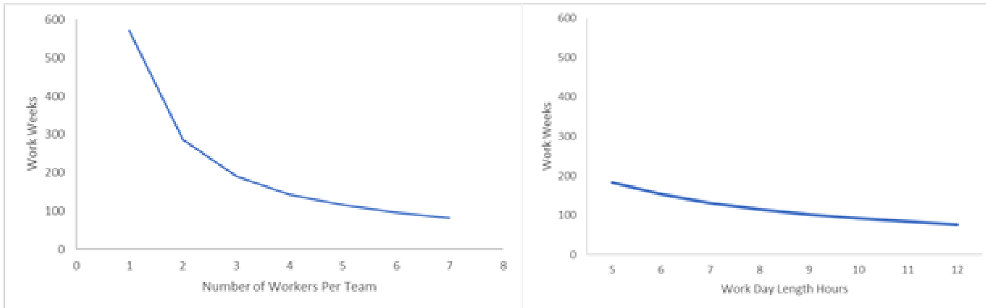

Figure 2. 1st Air Combat Aviation Brigade Case Study

Figure 2 depicts a case study done based on aircraft numbers that make up the 1st Air Combat Aviation Brigade. Looking at the 1st Air CAB is beneficial because it represents the type of problem that PM ASE is facing and shows the model's overall ability to estimate modification completion times for a large number of aircraft over an extended period. In this case study, specifically, the team looked at how varying the numbers of workers on a maintenance team affect the overall time it takes to conduct block modifications. As shown in the left graph in Figure 2, there are diminishing returns as workers are added to teams. This is because as the work is divided among more and more workers, each additional worker is taking on a smaller proportion of the total man-hours needed for an aircraft. It is important to understand that this model does not account for the impracticality of having too many workers in a maintenance team. Overloading team size will realistically result in decreased productivity although not depicted in the graph. This case study is beneficial to a decision-maker as it shows that, even when assuming multiple workers can work evenly at the same time, adding more and more workers will eventually not provide a proportional benefit compared to the cost of adding another worker to a team.

Similar to the first case study, which looked at the effect of varying the number of workers on a team on total work weeks, the team conducted another case study that varied the length of the workday. Similar to workers, adding more hours of work a day decreases the total time it takes to modify the Brigade. While both workday length and number of workers are inversely proportional to the total time to modify the Brigade, they each have different correlations. Increasing workers results in a steep decrease initially and levels out as more workers are added. In the right graph of Figure 2, the correlation between the length of each workday relates to the total number of workweeks needed to modify the Brigade is depicted. This line also sees a more substantial decrease in total time initially, however, it is much more gradual overall and almost linear. Looking at these individual case studies helps a stakeholder understand which variables affect the total time the most and give them more information for cost and benefit decision making.

Analyzing the sensitivity of a variable gives valuable information to a decision-maker or client. As seen in Figure 2, the number of workers assigned to a team has a much greater effect on the total work weeks needed to complete block maintenance than the hours a team works during a day. This is evident by the steeper curve presented in the workers per team graph. Conversely, the work hours per shift graph has a flatter more gradual curve. Therefore, increasing the number of workers initially has a greater effect on the number of weeks needed to complete a project. This information is valuable to stakeholders because it shows how changing a specific input in the model affects the output of the model. A decision-maker could use this information and analysis to understand how to change the model's parameters to shorten the time needed to meet deadlines. Understanding sensitivity also allows a decision-maker to understand the effects of limited resources or reducing costs has on the overall time needed to complete a project.

4. Conclusion

The ReARMM Modification Planner Capstone Team for AY22 developed a fully functioning program in Excel that optimizes both cost and time for modernizing aircraft in the Army. This is done by comparing the costs and schedules of modernizing these aircraft at both ReARMM Modernization Centers (RMCs) and particular Army bases around the country at which aircraft can be modernized. The team did so by using the Solver function in Excel to create an optimization process that takes multiple variables and constraints into consideration while optimizing. Overall, the planner can take inputs set by the user and produce outputs to give a clear view of how much the modernization of the aircraft or group of aircraft will cost and the associated schedule.

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