SIMULATION IN A BOX (A GENERIC REUSABLE MAINTENANCE MODEL)

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ABSTRACT

Simulation models can be time-consuming to build and often multiple models are built to simulate similar systems that have small differences. While developing a model to evaluate the impact of maintenance functions on the day-to-day operations of an Air Force Wing, thought was given to how the same concepts could be applied to other military and commercial maintenance operations. This simulation was designed specifically to support a model of Air Force Wing operations and the maintenance functions associated with them. The secondary objective was to ensure the simulation could evolve into a generic model with applications across the military and in the commercial world. This paper discusses considerations and challenges in designing and moving to a generic model. The current version of the model from the user's and modeler's view is also presented.

1 INTRODUCTION

The simulation model under development is called the Scalable Integration Model for Objective Resource Capability Evaluations, in short SIMFORCE. SIMFORCE is being developed under a Small Business Innovative Research (SBIR) program through the Air Force Research Labs. The emphasis of the SBIR is to apply Commercial Off The Shelf (COTS) products to provide cost effective solutions to the problems AF maintainers and logisticians face daily. The over-all objective was to provide a decision support tool that would allow logisticians to evaluate and measure the effect of logistics resource constraints on operational / production capability. The SBIR program requires that products developed under it have applicability in the commercial world. This paper discusses the background of the model development, the concerns in making it generic, and how the concerns were addressed. The paper also briefly describes SIMFORCE from the user's and modeler's perspective.

2 BACKGROUND

The initial SBIR request for a model such as SIMFORCE arose from the fact that logisticians in the Air Force have never had a method to quantify the impact of various operational and maintenance decisions and their effect on the mission capability together in a timely and easily accessible manner. There are models that simulate Wing operations or Wing maintenance, but none that consider all maintenance resources (people, equipment, vehicles, and parts) in one model. Previous research indicates that maintainability is critical in wartime operations and more critical than reliability (Powers 1983).

An objective of the SBIR is to provide logisticians with a desktop tool that allows them to evaluate "what-if" scenarios and become pro-active rather than re-active in their decision making process. Typical scenarios that needed to be considered included the following: 1. I am deploying to Incirlik, Turkey with 6 F-15E's. What numbers and kinds of technicians, crew chiefs, spare parts and support equipment should I take to fly 10 sorties per day? 2. I have been requested by higher headquarters to send six crew chiefs on temporary duty to Incirlik. What, if any, is the impact on my daily flying?

Another goal of this SBIR is to roll military technology into the commercial world. One of SIMFORCE's goals is to ensure that the basic model is generic enough to support a broad range of applications, including commercial applications. Initial requirements definition trips to military units and commercial operations showed that the maintenance process, i.e. inspect, operate and repair as needed, is in fact, relatively generic. Our goal was to build a "Simulation in a Box" capability that supports a wide variety of applications and operations.

Early in the research, criteria developed to evaluate the simulation product dictated the focus of the model design and determined the options for the selection of the simulation tool used to build the model. The model needed to operate on a desktop PC rather than requiring the computing power of an enterprise class server. The

model's intended users would be local maintenance decision makers (i.e. Logistics Group Commander, Plans and Scheduling Logistics Planning, etc.) so the model needed to be focused at the user level, not requiring familiarity with programming or simulation skills to run the model. It was essential that the interface to the user be simple and familiar. Because the model should be available to every unit, the cost had to be kept low.

Based on the above criteria, the simulation tool chosen for developing the model was Arena® (Kelton, Sadowski, and Sadowski 1998, Pegden, Sadowski, and Shannon 1995) by Rockwell Software (formerly Systems Modeling). Arena® provides the capability of a desktop PC simulation without the cost of a run time license. Arena® is integrated with Microsoft products and incorporates Visual Basic for Applications® (VBA) in its design. AF users and the commercial world are generally familiar with the Microsoft Office suite and VBA® provides a convenient means for handling input and output to the simulation.

3 WHAT IS GENERIC?

Our first task was to define what we meant by a generic maintenance model and what did we expect our generic model to do? The model would simulate the operations performed by or on an end item (e.g. an aircraft or production line) during its different conditions of use (e.g. normal, surge, overtime, peacetime, wartime). As the operations were performed, unscheduled (breakdowns) and scheduled maintenance would occur. Resources (people, parts, equipment, vehicles) would be used and/or consumed as the operations or maintenance was performed. The end item, operations, resources, and operation and maintenance schedules that the model would use would all be inputs to the model. Simply by changing the input data the model could produce results for a wide range of applications. The results would be predictions of the impact of availability of maintenance resources on the output rate (e.g. number of sorties, number of items produced) and costs of running any major system or end item at different operation rates. Pre-defined output charts would be provided, but the model would also output "raw" simulation results, so users familiar with the output tools could customize their data. From this fairly ambitious definition, we started our development.

4 DESIGN APPROACH AND MODEL CONSIDERATIONS

Building a generic model from scratch can be an overwhelming task and one that is a bit difficult to define. Our approach to achieving the end goal of a generic model was to consider the components and processes required in operation and maintenance, then to define overall structure

and bounds of the model and try to isolate functions that could be added incrementally. To better understand the maintenance process to be modeled and its scope, and to prove our concept, we first developed and built a model specific to the support of the core operation and maintenance functions of an F-16 fighter Squadron/unit (Brown, Crippen, Gossard, and Powers 1999). Figure 1 illustrates the main components in the operation and maintenance of a Wing that were used as a guide to identify individual components. All components except the two outlined in double lines are addressed in the current model. As development gives us more insight, we have been expanding functionality and changing the specifics into generics.
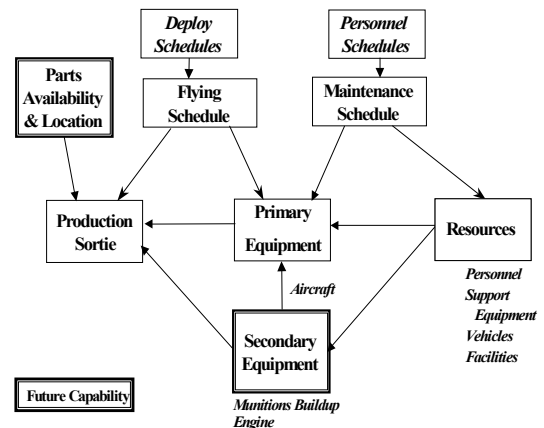

Figure 1: Overview of Wing Operations and Maintenance Components

To help define the structure and the bounds of the model we addressed several questions. These questions are discussed using the AF Wing model as the example of how we looked at each question.

4.1 What's Important to Model?

Models can quickly become very complicated and overly detailed (Lawrence and Mackulak 1998). We defined all the pieces of the Wing flying operation that are touched by maintenance functions and identified where maintenance had a critical impact on operations, i.e. identified what can severely impact a flying schedule or can grind the operations to a halt.

Flying in the Air Force follows a relatively stable process flow. Aircraft are inspected, flown, loaded and unloaded, depending on the type of aircraft and mission. For each process step, certain resources are consumed and there is a chance of failure, i.e. aircraft break, and Monte Carlo techniques can be used to evaluate these considerations. It was decided that the focus of this model would be on the resources (people, support equipment, vehicles, money, parts) necessary to support different

flying scenarios. The operations and support functions of the Wing would be modeled only as needed to determine resource use.

4.2 Flexibility and Setting Limits

Deciding what to model led to the question of flexibility. In what way should the model be flexible and how much flexibility should the model allow? This flexibility affects both the model developer/maintainer and the user. Since each aircraft Wing can have different types and numbers of resources that are critical to their operations, the user must be able to specify the ones that are important to them. The developer must provide a way for that to happen without a change to the model for every site. Different aircraft and production equipment also require different process steps requiring different resources and parts and different process times. Once the decision of what to model is made, the next decision is how many of each model component to allow the user to define.

In order to be a generic model it is necessary to give the user as much flexibility as possible in defining inputs to the model, such as aircraft, resources, process steps, failure rates, and processing times, that are specific to their sites and circumstances. However, it is also necessary to keep the model within a reasonable size and scope (Kelton and Law 1991). It was decided to establish limits based on the most likely configuration of a Wing. These limits affect the numbers of aircraft, resources, process steps, and systems and can be easily increased if necessary.

4.3 Fidelity (Accuracy) vs. Speed

Fidelity vs. speed is a question of how much detail can you afford to capture and still be certain that the simulation run time will be short enough to meet the needs of the decision maker. Three of the fidelity vs. speed factors we considered were associated with aircraft discrepancies, technical skills, and tracking parts. For aircraft discrepancies, it was decided to only model the discrepancies that kept the aircraft from accomplishing its mission. Many other discrepancies are documented for potential problems that may limit capability, but which still allow the primary mission to be accomplished. For technical skills, the Air Force maintenance technicians have three primary skill levels that limit their utilization and indicate their experience and productivity. For this factor, a simple formula was devised to divide the technicians according to skill and calculate productivity which equates to personnel equivalents. Availability and productivity are varied by the skills available. For tracking parts, it was found that the top 400 parts included 95% of the costs and 90% of the down time. Currently, SIMFORCE only tracks those top 400 parts, however there

are no limitations to the number that could be tracked. The only trade off is speed.

4.4 Input Considerations

Input considerations need to be looked at from several angles. What should be input to the model and what form should it be in? How is the input handled so that one design handles any amount or size of input? Can the input be structured so that it can be easily replaced by or connected to a database?

One of the prime concerns of building this simulation, was how to input essential data on operations tempo/production requirements, the current status of the aircraft/equipment being maintained, and the availability of supporting resources. Ideally, this information should come from supporting legacy systems, but because of limited SBIR funds these connections cannot be made for SIMFORCE. Some input data is relatively stable, such as failure rates for a specific type of aircraft or equipment, but availability of data varies considerably. Fairly accurate status and availability data is important to achieve accurate results.

Due to the volume of input data required, it was decided to provide default values for all the input and allow the user to modify it with more accurate local data. The original set of default input is for F-16s obtained from operational AF bases (e.g. for tail numbers and flying schedules) and from existing AF data systems (e.g. for failure rates).

We chose Excel® for the majority of our input for many reasons. Based on site visits, we know that most SIMFORCE potential users and even maintenance users are familiar with Excel®. Many local Wing managers use Excel® spreadsheets to maintain status on aircraft and technicians. Additionally, the VBA® that is integrated into Arena® allows for the easy manipulation of the Excel® input data into formats useable by the simulation engine. Using Excel® also allows for pre-defined default values to be entered and gives the user the option of using the default values or entering more accurate local data.

Looking to the future, Excel® also can be populated from a database. The Excel® worksheets are defined in logical entity-attribute type groupings that lend themselves to a smooth conversion to a relational type database.

As a side note, the newest version of Arena®, version 4.0, makes use of the MS Access® database, which may prove useful in the future development of database connections for input and output data.

4.5 Output Considerations

Even though input considerations tend to be complex because of the availability and access to this data, output data, from a development standpoint, is even more

complex. At the beginning of the simulation run, neither the user nor the developer may know what needs to be shown to demonstrate the constraint to the operation. What resource is critical may not be obvious before the run. The format of the output results presents another problem of trying to determine what output format most clearly shows the constraint. Different constraints may be highlighted more effectively in different formats such as graphs, trends, pie charts, or just data.

Making the model generic adds to the complexity of the problem. Being generic allows the user to define and change the resources (in any order) that will be modeled, so the critical resources can be different for each application or for different scenarios within the same application.

Since the user is familiar with Excel®, the decision was made to also use Excel® as the repository of all the output results of possible interest to the user. Different categories of data are assigned to different worksheets and the worksheets are populated with the raw output data at the end of a simulation run. Several standard default graphs are created from the raw data showing the 10 highest criteria values for the particular plot. Experienced Excel® users have the ability to graph the raw data to fit his/her own needs. We are still in the process of gathering user feedback and revising the output.

4.6 Future Considerations

Some consideration was also given to possible future enhancements to the model beyond the scope of the SBIR. These future possibilities include connecting to data bases for input and output, building a web browser GUI for input and output, figuring environmental factors into system failure predictions, incorporating dynamic rescheduling with estimated times to repair, incorporating major component (e.g. engine) maintenance, allowing multiple models of an end item (e.g. Mission Design Series, such as F-16 or C-130) in one simulation run, changing the configuration of the end item based on the operating schedule, adding time critical unplanned maintenance (e.g. Time Critical Technical Order (TCTO)), and automating multiple runs of a simulation varying a parameter. Future possibilities geared more to the military include figuring weight and cube into deployment cargo alternatives and adding weapons build up and availability factors.

5   SIMFORCE DESCRIPTION

The "Simulation in a Box" idea was to develop a simulation "engine" that was invisible to the user which would simulate operations and maintenance scheduling while focusing on resources (personnel skills, support equipment, vehicles, parts) consumption. The "box" would accept input about operation and maintenance

functions and resources, and would output predictions of resource needs, failures, and production sorties and costs.

Figure 2 is a high-level depiction of the SIMFORCE architecture. This figure helps illustrate both the components described in the remainder of section 5 and the user and modeler's perspective of the SIMFORCE model.
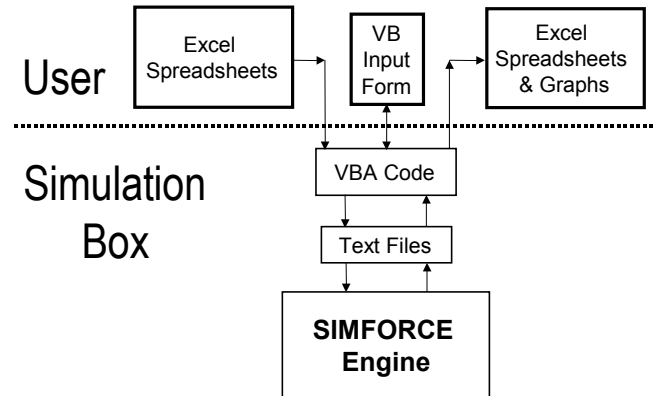

Figure 2: SIMFORCE Architecture

5.1 Input

The input to SIMFORCE defines the application that is being modeled. It controls the timing and duration of the simulation run.

5.1.1 User's View

The user defines the end item and its characteristics that affect processing (i.e. aircraft, its model, serial number, and configuration), the processing steps it goes through (i.e. crew chief walk around, air crew pre-flight, etc.), and the resources required to support the processing steps and to fix the aircraft.

Input to the model is currently in two forms, an Excel® workbook and VB® forms. The Excel® workbook is formatted to identify the data needed by the model and populated with default data for a particular application of the model. The input in the Excel® workbook is grouped on worksheets in logical divisions. The Excel® workbook values are generally filled in before a simulation run but can be changed at the beginning of a run.

The other input is through Visual Basic forms that are displayed when the simulation begins and provides additional values that control the timings of simulation events and length of the simulation run.

The worksheets in the Excel® workbook include the following:

End Item Data – contains information for the end item along with the characteristics that affect processing. For the Wing model, this sheet

contains tail number, (unique identification numbers for the aircraft / equipment, Type Equipment, configuration, and status of each aircraft in the unit.

Major Component Data – contains information for a major component and its status. For the Wing model, this sheet contains engine number and status of each engine owned by the Wing.

Resources Data - contains information for all resources the user deems critical to the operation and maintenance of the end item along with the resource pool size and failure data. For the Wing model, this sheet contains resource name, pool size and failure data for all the maintenance resources needed to fly and maintain the aircraft.

Deployment Data – contains information for any planned extended length of time end items and resources are unavailable. This data represents the end items and resources that are unavailable to normal operations for the time indicated. For the Wing model, this sheet contains names of planned deployment with the tail number of the aircraft being deployed and the start day and duration of the deployment.

System Data - contains information for all major systems of an end item that are critical to operation or have a high impact on maintaining a schedule. For the Wing model, this sheet contains system name, system failure rates, and resources needed to fix a broken system along with the average length of time the resource is needed.

Parts Data - contains information for all parts of the defined systems that are critical to operation, have a high impact on maintaining a schedule, or are a high cost item. For the Wing model, this sheet contains part name, part failure rates, average replacement/fix times and usual part cost.

Step Data - contains information for process steps through which the end item goes along with the resources needed to perform the step, failure rates of the end item at each step, and processing times for each step. For the Wing model, this sheet contains names of process steps, such as Crew Chief Walk Around, Air Crew Pre-Flight, Fly Mission, etc., along resources and quantity needed, such as one Crew Chief and one Air Crew for the Air Crew Pre-Flight step, type of distribution (default Triangular) to model the step and distribution parameters.

The user can change the Excel® data provided as defaults by saving the protected Default workbook to another name and making changes to the data. The user can do this at any time before a simulation run or when the simulation begins. When the simulation begins, the user can specify which workbook to use for input data.

The Visual Basic® forms allow input of a production schedule and timing parameters affecting the schedule. For the Wing model, schedule is a flying schedule with options to fly by a turn schedule, fly by a Utilization (UTE) rate, or fly the maximum number of aircraft. Timing parameters include take-off times, launch size, and launch interval. Other timing values that can be specified are workdays per week, shifts per day and the number of days to run the simulation and the number of replications.

5.1.2 Modeler's View

The data supplied on the input Excel worksheets and through the VB form is converted to numeric data for use by the SIMFORCE engine (Arena simulation model). The conversion in done via VBA code inserted in the Arena default VB subroutines RunBeginSimulation and Run-BeginReplication. Some of the data is loaded directly into Arena variables, while some is put in text files that are read by the model as it executes. Text files include data such as resource schedules and system and part failure rates.

5.2 The SIMFORCE Engine

The SIMFORCE engine is the Arena model.

5.2.1 User's View

From the user point of view, the model is essentially a black box, hence "Simulation in a Box". The user feeds input into the box and receives output results from the box. The user does not need to build a model or change the model logic to set up the model for his/her application. The boxes above the dashed line in Figure 2 outlined by the bold lines identifies the parts of the SIMFORCE architecture that the user sees and uses.

When the user defines the inputs to the model, he/she is defining the application that is being modeled. The user needs only to understand that the chosen end item (i.e. aircraft) goes through a series of process steps and that the systems and parts data input to the model are systems and parts of the end item.

5.2.2 Modeler's View

In the model, the aircraft defined on the input sheets become the entities that are processed through the processing steps (also defined on the input sheets). The engine sends the aircraft through the steps at a rate specified by the schedule entered on the VB form. (For an operational Wing these are steps like Pre-Flight Check, Crew Show, Take-off, Debrief, etc.) The same schedule is flown for each simulated day. At each step the aircraft

use/consume resources for a period of time determined by the aircraft model and configuration, and whether it is doing a turn. (For example, for the Pre-Flight step an F-16 may need a crew chief for 2 hours on the first flight, but only 45 minutes on a turn flight.) If a step is not needed on a particular simulation run, its process time can be set to 0. Step duration times are calculated using a triangular distribution provided by Arena. There is also a probability of a break in the aircraft at each step which will require resources to fix. Break probabilities, step duration parameters, resources needed at each step, etc. are all defined on input sheets.

When there is a break each aircraft system defined on the input sheet (e.g. Engine) is checked independently to see if a break has occurred in that system. (One or more systems can break at the same time or there can be a CND – Could Not Duplicate – condition.) For each system that is broken, each part defined for that system is checked independently to see if a break has occurred in that part (e.g. EMSC Computer). None, one, or more than one part can break at the same time. If any systems and/or parts are broken, the aircraft is put in a broken (NMC) status and a spare is substituted for the broken aircraft. A delay time is determined to replace or repair any parts. Delay times for parts are calculated using a lognormal distribution provided by Arena. After all parts are received, the resources needed to fix the systems/parts are seized for the time required to do the fix. The aircraft is then put in flying (FMC) status and returned to the process step to prep it for its next flight.

The model calculates when aircraft will go to scheduled (phase) maintenance and when aircraft and resources will be deployed, again, based on input data from the Excel workbook. Phase results in a reduction of the number of aircraft available to fly. Deployments result in a reduction of the number of aircraft and resources that are available to the current Wing mission. Resources each have their own random failure rates and repair times that affect their availability. Each resource defined on the input sheets becomes an entity with its own processing loop that reads its own schedule and defines its own random failures.

The model also has an End of Day loop that determines the end of a simulation day and writes the simulation statistics for each day to a text file for later processing by VBA into Excel output.

5.3 Output

The output displays the simulation results in a user-friendly form. The pre-defined graphs and charts are what we expect to be the most useful to the user.

5.3.1 User's View

When the simulation run ends, an Excel® workbook is automatically opened which contains the output results collected during the simulation run. There is a worksheet for each different set of "raw" data collected during the run. Additionally, for each "raw" data worksheet there is a worksheet depicting the data either in graphs or as totals. For the Wing model the output worksheets are sorties per day, aircraft status by day, resource utilization by day, resources not available per day, wait time for resources per day, part failures per day, and cost information.

5.3.2 Modeler's View

The simulation results written out to text files by the SIMFORCE engine are converted to character (i.e. resource 10 = Crew Chief) data where needed and processed into Excel charts and graphs. The conversion in done via VBA code in an Excel worksheet used as a template to format the output. Most of the output is calculated from counters and tallies built into the model and not supplied by Arena.

6 MOVING TO THE COMMERCIAL WORLD

One of the truths discovered during the requirements definition phase of this project was the similarity in the process of maintaining and supporting major equipment. This conclusion is also validated by years of employee experience in both the commercial and military areas. Major pieces of equipment used in operations and requiring maintenance can be anything from a General Motors punch press, to a boat to aircraft. All of this equipment is inspected, operated, and somewhere in the process steps, it may break. When a break occurs, specific resources are necessary for repair, and repair times vary by the system broken. Since the SIMFORCE engine is basically set up as a shell of process steps, entities, and variables that are populated by user input, the user has tremendous flexibility in defining applications in two ways. One is to set up applications for different systems or end items (e.g. Wing operation and a door press plant), and the other is to use the same application at different sites with site-specific data (e.g. Wing operation for F-16 and Wing operation for F-15).

In the commercial world, aircraft become end items, engines become major components, flying schedules become production schedules and deployments become scheduled periods of unavailability of certain end items and resources. Resources, systems and parts of an end item, and processing steps have a universal meaning.

To test our theory of maintenance similarities on our model, we have set up input for the model that describes a GM press plant that produces right side truck doors. In this application an aircraft becomes a press line, resources are pipefitters, electricians, die maker, operators instead of crew chief, air crew, avionics A specialist, etc., systems on the press line are destacker, robotic arms, presses, and stacker, and only one step is needed to run the line. Output of number of sorties becomes the number of doors produced. The GM plant input verifies that a very different but similar application to a Wing operation can be simulated by only changing input to the SIMFORCE engine without changing the engine itself. However, we have not obtained enough data from the GM plant to verify our output results.

7 LESSONS LEARNED

Some of the lessons learned are the age-old lessons that are re-enforced with every software development project. Foremost, is that it is always difficult to get timely and accurate test data. Our problem was compounded by the generic nature of the model, which required large quantities of input. A substantial amount of time was consumed in setting up and manipulating data. When showing the model to customers we found that their initial reaction was being overwhelmed by the amount of data required and the concern of who would set it up. It has been difficult to convince people that once the initial data is analyzed and entered, minimal time is required to maintain it.

The volume of required input has also made it difficult to validate the model. With so much variability in the data, it has been difficult to confirm that the model reflects real life.

Suggestions that we would make for building a generic model are to set reasonable/realistic bounds on allowable number of inputs and to weigh value of what needs to be modeled and detail needed.

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