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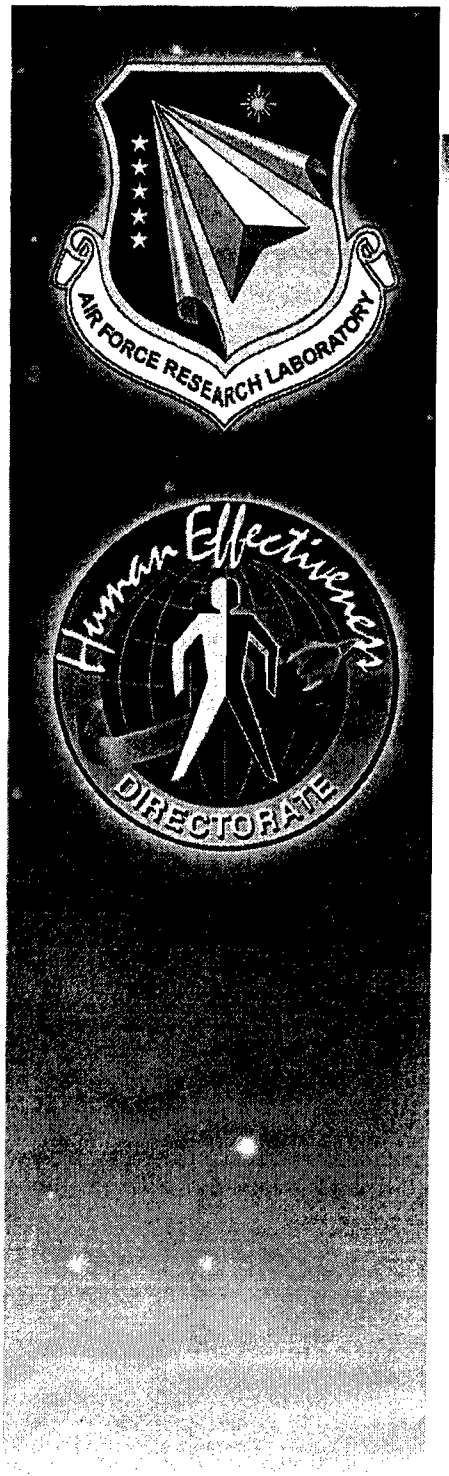

AIR FORCE RESEARCH LABORATORY

Modeling Sortie Generation for Unit-Level Logistics Planners

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January 2005

Interim Report for November 2002 to January 2005

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FOR THE COMMANDER

//SIGNED//

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14. ABSTRACT

This research demonstrated that simulation could provide valuable information for decision-making at the unit-level and provide much needed assistance in the generation and execution of a weekly flying schedule. In previous research a simulation model detailing an Air Force Multi-Indenture Multi-Echelon (MIME) repairable parts system was developed. That simulation model was used to explore the effects of using commercial shipping practices on the supply chain. This research expanded the simulation model developed for the commercial transportation project to detail the sortie generation process. Using this simulation the effective risk inherent in a given weekly schedule was evaluated. The concept was to allow until-level logistics planners to input a weekly schedule and to evaluate that schedule based on outputs received from the simulation. A model of this type also allows the unit-level logistics planners to compare alternative schedules and perform what-if analysis.

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EXECUTIVE SUMMARY

This research demonstrated that simulation could provide valuable information for decision-making at the unit level and provide much needed assistance in the generation and execution of a weekly flying schedule. In previous research a simulation model detailing an Air Force Multi-Indenture Multi-Echelon (MIME) repairable parts system was developed. That simulation model was used to explore the effects of using commercial shipping practices on the supply chain. This research expanded the simulation model developed for the commercial transportation project to detail the sortie generation process. Using this simulation the effective risk inherent in a given weekly schedule was evaluated. The concept was to allow until level logistics planners to input a weekly schedule and to evaluate that schedule based on outputs received from the simulation. A model of this type also allows the unit level logistics planners to compare alternative schedules and perform what-if analysis.

There are significant challenges in developing a tool that is useful at the unit level. First, the user interface must be such that the planners can quickly and easily input the needed data. If the user interface is too complex or confusing no value will be added to the decision process. Second, the simulation must be detailed enough to provide useful outputs to the user, but also simple enough that the simulation time and data requirements are minimal.

This research began by reviewing the relevant literature, systems, and processes. Part of the goal was to illustrate how simulation could be used in this context. Thus, military logistics, MIME systems, and user interface systems required review. Likewise, the project provided a detailed description of the simulation model along with the user interface system and a description of data handling methods. In addition, a test scenario was outlined along with detail on how the model handles this scenario from user input to interpreting the output data.

Examples of what-if analysis that can be performed using the same test scenario were also developed. Through the execution of this test scenario, the research demonstrated how this type of simulation technology could be useful in making decisions at the unit level. The outputs will provide the user valuable assistance in making timely decisions that can mitigate the risk associated with executing a flying schedule.

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Acronyms

CAMS	Core Automated Maintenance System
DSS	Decision Support System
ESL	Expected Sortie Length
LRU	Line Replaceable Units
LTL	Less than Truck Load
MC	Mission Capable
METRIC	Multi-Echelon Technique for Recoverable Item Control
MICAP	Mission Incapable Awaiting Parts
MIME	Multi-Indenture Multi-Echelon
MTTF	Mean Time to Failure
NMC	Non-Mission Capable
PI	Phase Inspection
SRU	Shop Replaceable Units
TTF	Time to Failure
TUR	Time until Release
TUT	Time until Takeoff
USAF	United States Air Force
WG	Wing

1 Introduction

In this research our goal is to demonstrate that simulation can provide valuable information for decision-making at the unit level. In previous research, we developed a simulation model detailing an Air Force Multi-Indenture Multi-Echelon (MIME) repairable parts system. We used this simulation model to explore the effects of using commercial shipping practices on the supply chain. We expand the simulation model developed for the commercial transportation project to detail the sortie generation process. Using this simulation, we evaluate the effective risk inherent in a given weekly schedule. The concept is to give until level logistics planners the ability to input a weekly schedule and to evaluate that schedule based on outputs received from the simulation. A model of this type also allows the unit level logistics planners to compare alternative schedules and perform what-if analysis. Due to the fact that much of the model has remained the same, we have omitted certain model details. Please refer to our previous report if more explanation is desired. Our goal for this report is to concentrate on the new material we have developed.

There are a number of challenges in developing a tool that is useful at the unit level. First, the user interface must be such that the planners can quickly and easily input the needed data. If the user interface is too complex or confusing no value will be added to the decision process. Second, the simulation must be detailed enough to provide useful outputs to the user, but also simplistic enough that the simulation time and data requirements are minimal.

In this report, we begin by detailing the relevant literature, systems, and processes. Part of our goal is to illustrate how simulation can be used in this context. Thus, we must discuss military logistics, MIME systems, and user interface systems. The next section of this report details our modeling approaches. In this section, we provide a detailed description of the

simulation model along with the user interface system. We also included in this discussion a description of our data handling methods. Finally, we outline a test scenario, and detail how the model handles this scenario from user input to interpreting the output data. We also show example what-if analysis that can be performed using the same test scenario. Through the execution of this test scenario, we demonstrate how this type of simulation technology can be useful in making decisions at the unit level. The outputs provided to the user will assist them in making timely decisions that can mitigate the risk associated with executing a flight schedule.

2 Sortie Generation and the MIME Repairable Inventory System

Our previous report concentrated on the logistical aspects of the Multi-Indenture Multi-Echelon (MIME) repairable parts inventory system used by the United States Air Force. In our previous research we modeled the MIME supply chain in detail. In this research we look at the sortie generation process that is supported by the MIME supply chain. In the following sections, we will give a brief description of an MIME repairable parts system.

2.1 MIME Repairable Parts System

In this research we will use the previously developed MIME supply chain model. Multi-echelon refers to the fact that inventory is kept and repaired at multiple levels in the supply chain (i.e. depot, bases, and weapons). This structure can be seen in Figure 1. At each echelon actions are performed. These actions have an increasing level of sophistication as a part progresses up through the levels. Sometimes the echelons are simply distinguished by their unique geographic location in relation to the previous level. The USAF has a two-level maintenance system, where the first echelon is maintenance performed on base and a second echelon where maintenance is performed at more specialized and sophisticated depot.

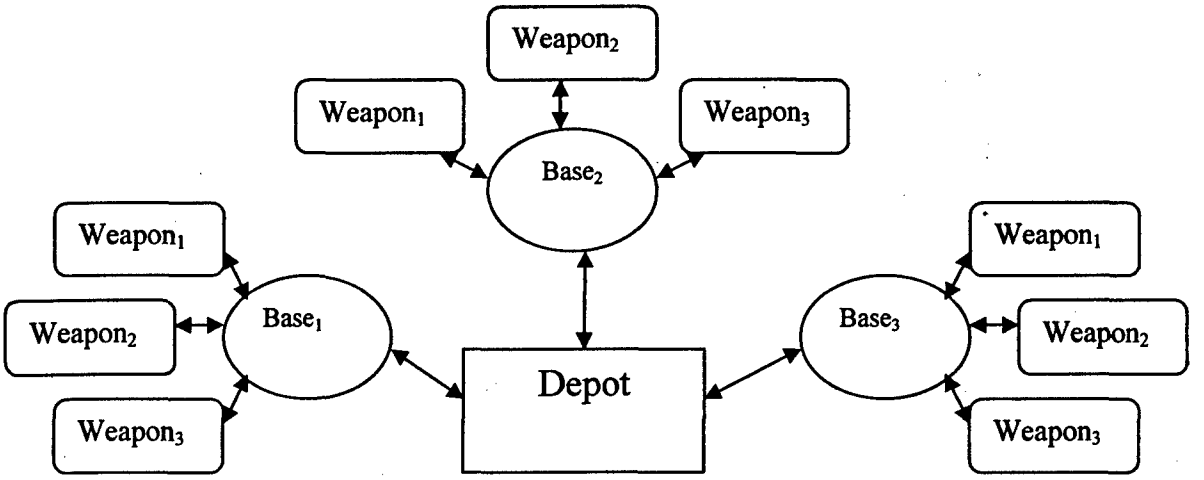

Figure 1: Multi-echelon system

Figure 1 depicts a depot that supports three bases ($Base_1$, $Base_2$, $Base_3$), each of which supports three weapon systems ($Weapon_1$, $Weapon_2$, $Weapon_3$). This system can be expanded, in theory, with additional bases, weapons, and depots.

Parts moving through the system are composed of components and those components are in turn made up of sub-components. The parts are said to be multi-indentured because of this stratification of components. In this context, a first-indenture component that is removed from an aircraft is called a line-replaceable-unit (LRU) because this activity takes place on the flight line. LRUs are usually repairable or recoverable and they tend to be expensive, with low demand at any particular base. When a first-indenture item is taken apart in a maintenance shop, second-indenture items are replaced; these are called shop-replaceable units (SRUs). When an item fails, it takes time and expertise to diagnose and replace the SRUs that are responsible. It may take specialized test equipment, and it may require sending the item to the next-higher echelon or depot. This extra time translates into aircraft downtime. For example, a fighter maintenance squadron will spend up to 13 hours of maintenance for every one hour of flight time.

For this research, a weapon is conceptualized as an aircraft. Each weapon is made up of multiple components called line replaceable units (LRU) shown in Figure 3. LRUs are, in turn, made up of multiple sub-components called shop replaceable units (SRU). In Figure 2, the subscript i denotes the LRU for which the SRU is a subcomponent, while j denotes the SRU type.

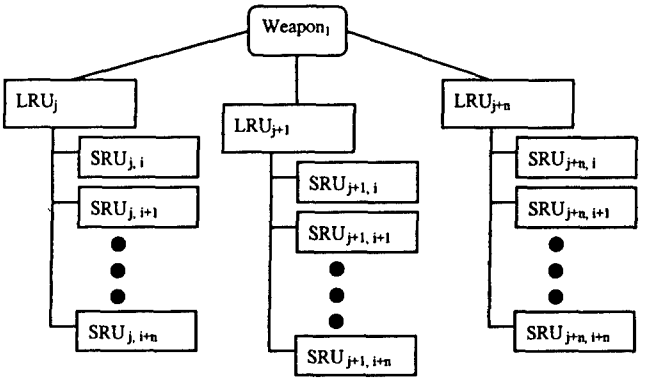

Figure 2: Hierarchy of Weapon System

2.2 Failures

A weapon incurs downtime when one of its LRUs fails. An LRU fails when one or more of its component SRUs fails. When a failure occurs, the failed LRU is removed from the aircraft and sent to repair. Each base has a limited repair facility for failed parts and a warehouse to store a limited amount of inventory. The typical failure cycle of a simple, single echelon base is shown in Figure 3. Note that every spare part shown is not necessarily the same part that originally failed. The representation of the failure cycle and repair process becomes more complicated than that depicted in Figure 3 when we move to a MIME system.

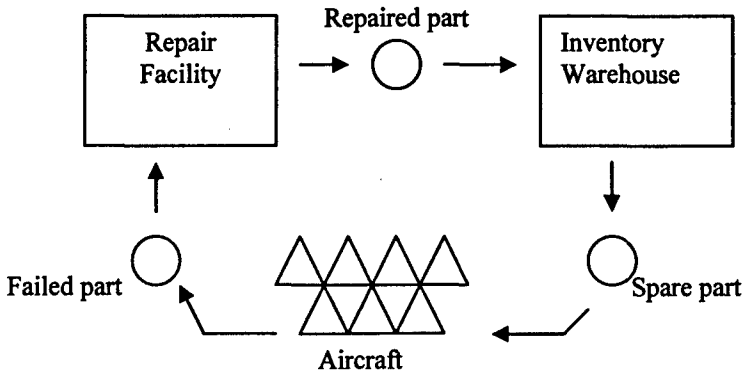

Figure 3: Failure Cycle and Repair Process

2.2.1 LRU repair at the Base level

As described above, the failed LRU is removed from the weapon and sent to an intermediate repair shop. At test stations, technicians perform a battery of tests to determine the problem. Sometimes, the LRU can be fixed by straightening pins, cleaning connections, replacing fuses, re-soldering connections, or re-calibrating. But often, tests reveal that repair requires the replacement of a failed SRU. Once the defective SRU is determined, two things can happen:

1. If a spare SRU is available in the base's inventory, the defective SRU is swapped with the spare. The defective SRU is either repaired at the base level and put back into inventory, or is sent to the depot for repair. If the SRU is sent to the depot for repair, an order is generated for the part.
2. If a spare SRU is unavailable in base inventory, the defective SRU is sent to the depot for repair and an order is generated for this part. The order is marked to indicate that the aircraft from which the defective SRU was removed is non-mission capable awaiting parts (MICAP). This designation indicates that express-air shipping will be used.

In both scenarios, base-level repair is characterized by swapping the failed SRU with a serviceable SRU, called filling the LRU hole. Also, in either case, if a defective SRU is sent to the depot for repair, an order corresponding to that SRU type is sent to the depot. The order is filled from depot inventory and shipped back to the base to replenish its inventory.

2.2.2 SRU repair at the Depot level

If a base cannot repair a failed SRU, the base sends it to the depot for repair. Upon receipt of a SRU from a base, the depot will send the base a serviceable SRU. The SRU received from the base will be inducted into the depot's repair process and upon repair will be retained in the depot's inventory

The depot tries to maintain a constant level of inventory for itself and the bases, in keeping with the aforementioned base stock inventory policy. From the depot's standpoint, whenever a defective part is received, a serviceable part is shipped. Similarly, from the base's standpoint, whenever a defective part is shipped, a serviceable part is received.

2.3 Transportation

The MIME inventory and repair system must also account for the transportation of parts between depots and bases. In this research we will only model the two traditional ways for shipping parts in an Air Force supply chain: less-than-truckload (LTL) and MICAP (expedited shipping). LTL shipments of parts are made on a daily bases between the depot and the bases, and MICAP shipments are made when the shipment must be expedited according to preordained specifications. For a more comprehensive explanation of shipping practices please refer to our previous research report.

2.4 Previous MIME Models

The MIME system has been the focus of much research over the years. A review of the literature shows that most of this research has been devoted to the development of mathematical models that explore redistribution of resources, suggest the optimized allocation of stock and offer a means of system evaluation. These models trace their roots back to a paper by Sherbrooke (1968) in which he introduces METRIC (Multi-Echelon-Technique-for-Recoverable-Item-Control). The basic model tries to optimize stock level of items at a given echelon. It is depicted in Equation 1 "Basic Stock Level" (Adapted from Sherbrooke, 2004).

Stock Level = (number of units on hand) + (the number of units due in from repair or re-supply) – (the number of units on backorder) **(1)**

See for example the models developed by Muckstandt (1973), Nahmias (2001) Slay (1984), Slay et al, (1996), Graves (1985) and Sherbrooke (1986) or for a general overview of all models see Kennedy, et al (2002). METRIC is not a true MIME model; it focuses in on the multi-echelon nature of the supply chain not the multi-indentured characteristic of the components. The model does lay the cornerstone assumptions for the later models. Some of these assumptions include:

- There is no lateral supply between bases
- There are no condemnations (all failed components are repairable)
- The level (base or depot) at which the repair is performed depends only on the complexity of the repair
- There is no waiting or batching of components before a repair is initiated

These limiting assumptions hamper their ability to provide detailed insight into the workings of the system. METRIC and similar models are generally concentrated on the mathematical optimization of the inventory costs and service levels associated with a potential spares inventory

policy, safety stocks and so on. Unfortunately, most of these methodologies are too complex, abstract or oversimplified, thus reducing their usefulness for a maintenance manager (Braglia et al, 2004) like the Production Supervisor.

The literature regarding the MIME inventory system (namely the models built on Sherbrooke's METRIC (1968) and Muckstadt's model METRIC (1973)) makes a number of simplifying assumptions. One of these assumptions relaxed in our model is:

- SRU and LRU Failures. Both Sherbrooke (1968) and Muckstadt (1973) assume that a failed weapon is the result of *only one* failed LRU and that a failed LRU is the result of *only one* failed SRU. However, since parts can often fail in clusters, as the failure of an LRU can cause the failure of another LRU, it is more appropriate to disregard this assumption. In our model we allow multiple LRUs to fail.

3 Literature Review of Sortie Generation

The sortie generation process consists of two main parts: planning and execution. The first part involves a sortie plan that is revised at the yearly, quarterly, monthly, and weekly basis where it emerges as an executable schedule of events. In the following sections we will review both of these two main parts to the sortie generation process. A large portion of the information below was taken from United States Air Force Instruction Document AFI21-101 (2002).

3.1 Planning

The planning process is an iterative negotiation process in which operations informs maintenance about their requirements, and maintenance reviews their capacity and informs operations about what they can provide. This process happens at many different levels of the command chain over the period of a year finally resulting in executable weekly schedules.

3.1.1 Annual Plan

The annual plan is a coordinated effort between operations and maintenance. The goal of this plan is to "evaluate the capability of maintenance to support the annual flying-hour program". Both the number and length of sorties along with the maintenance requirements are examined in attempting to devise a plan that will meet the UTE rate standards/goals.

Provided in this plan are:

- Airframe, personnel, and facility capabilities
- Required flying hours, estimated sorties, and missions provided in monthly increments
- Flying days by month
- Aircraft/Aircrew requirements
- Known and projected Temporary Duty and Special Missions Requirements
- Configuration and Munitions Requirements
- Programmed Depot Maintenance, depot, and transfer schedule
- Established number of available by month
- Estimated monthly attrition factor
- Recommended block scheduling pattern to meet requirements
- Statement of limitations

3.1.2 Quarterly Plan

The quarterly plan addresses the ability of maintenance to meet the established plan for the quarter laid out in the annual plan. Scheduling is called upon to ensure that the quarterly plans are as detailed as possible. It is important to note that a rolling 3-month plan briefed each month at the monthly meeting will suffice to fulfill the quarterly planning requirement. The intent of

the quarterly plan is to further develop the long-range plan initiated in the annual planning session.

3.1.3 Monthly Schedule

The monthly plan is intended to add further detail to the quarterly plan. The monthly plan is required to "forecast and monitor requirements for the current month and next two months." The monthly schedule will detail the total number of sorties, attrition sorties added, and the number of sorties for each unit. This monthly plan is developed over the course of the month proceeding the month being scheduled.

Specifically:

- Week 1 – Estimated operational needs for the following month are provided in as much detail as possible. This is meant to include times for takeoff, landing, and flying windows.
- Week 2 – Maintenance tells operations whether the requirements for the next month can be met along with the limitations that may prevent the fulfillment of the requirements. Any needed adjustments are made to bring agreement between operations and maintenance requirements.
- Week 3 – At this point operations and maintenance formalize the next month's schedule prior to presenting it to the wing (WG) commander.
- Week 4 – Upon the WG commander's approval, the monthly schedule is published and distributed no later than 5 days prior to the beginning of the planned month.

Included in the monthly schedule are:

- Detailed utilization calendar specifying total aircraft flying hours, total sorties, missions, alert requirements, scheduled sortie and mission requirements, daily turn plans for each mission design series.
- Maintenance workload requirements
- All scheduled aircraft inspections
- Total ordinance requirements
- TRAP requirements
- All support requirements i.e. supply requirements, food service requirements, etc…

3.1.4 Weekly Schedule

"Weekly scheduling is the final refinement of the monthly plan and results in the weekly flying and maintenance schedule." The weekly schedule is distributed no later than 1200 Friday morning before the effective week and includes:

- Aircraft takeoff and landing times including aircraft tail numbers (primary and spares)
- Sortie sequence numbers
- Configuration requirements
- Munitions requirements
- Fuel loads
- Special or particular mission support requirements
- Alert requirements
- Exercise vulnerability
- Deployments
- Off base sorties
- Equipment training requirements

3.1.5 Changes to the Weekly Schedule

In executing the weekly schedule there are many things that could happen to result in further planning or manipulation of the schedule. There are three types of changed which can be made to the weekly schedule after its distribution:

- **Pen-and-Ink** are intended to allow for minor changes to the weekly schedule which arise due to fluctuation in aircraft availability. Allowable changes include tail numbers, takeoff/landing times, etc…
- **Interchanges** or swapping tail numbers are intended to prevent unnecessary reconfigurations and expenditure of work hours.
- **Configuration** changes in the required configuration of units can be made to reduce man hours as long as the requirements of the sortie can be met.

3.1.6 Flying Schedule Deviations

The recording of schedule deviations is only applied to the printed weekly schedule. We refer the reader to Air Combat Command (ACC) Instruction 21-165 for a complete listing of deviation scenarios. These deviations directly impact the measures of scheduling effectiveness. There are multiple types of schedule deviations that are grouped into two categories as follows.

Ground Deviations

- Addition – The addition of an aircraft/sortie to the schedule not previously printed on the weekly schedule.
- Cancellation – An aircraft that is removed from the printed schedule for any reason.
- Early Takeoff – A scheduled sortie launching more than 30 minutes prior to the scheduled takeoff time.

- Ground Abort – An event preventing a "crew ready" aircraft from becoming airborne. A ground abort by itself is not a deviation, but can cause a deviation in the form of a cancellation of late takeoff.
- Late Takeoff – A scheduled sortie launching more than 15 minutes after the scheduled takeoff time.
- Spare – A spare aircraft launched instead of the scheduled aircraft.
- Interchange – Tail number swaps can be made up until the crew ready time.

Air Deviations

- Air Abort – A sortie which cannot be completed after takeoff for any reason. Air aborts are considered a sortie flown when reporting total sorties.
- Air Abort, IFE – An air abort resulting in a in-flight emergency
- Early Landing – A sortie landing more than 15 min before the scheduled landing time (not used when computing FSE).
- IFE – A situation resulting in an in-flight emergency after the mission has been accomplished.
- Late Landing – A sortie landing more than 15 min after the scheduled landing time (not used when computing FSE).

3.1.7 Flying Schedule Deviation Causes

Each deviation from the weekly schedule is required to be assigned a primary cause. The primary cause categories of interest are as follows:

- Maintenance – Deviations resulting from unscheduled maintenance.
- Supply – Deviations resulting from a Partially Mission Capable or Not Mission Capable condition due to lack of supply.

- Weather – Deviations due to severe weather.
- Sympathy – Deviations resulting from aircraft deviations within a scheduled group of aircraft.

3.1.8 Schedule Exceptions

Exceptions are defined as allowed schedule deviations. The situations in which schedule exceptions are as follows:

- Adverse Weather – Sorties can be added to make up for cancelled sorties due to severe weather. This number cannot exceed the difference between the actual sorties canceled and the planned attrition number.
- Achievement of Utilization Rate – The operations group commander is encouraged to modify or cancel all or part of the schedule when they are reasonably assured the UTE rate goal for the month will be met.

3.1.9 Flying Schedule Effectiveness

Equation 2 details the calculation for Scheduling Effectiveness. Deviations have a major impact on this metric and are avoided by using the ability to change the weekly schedule while it is being executed. Changing the schedule while it is being executed is complicated due to the high number of factors at play and the far reaching consequences for the unit based maintenance planners.

$$Total\ Sorties\ Scheduled = Home\ Base\ Schedule$$

$$Scheduling\ Effectiveness = \frac{Total\ Sorties\ Scheduled - Total\ Deviations}{Total\ Sorties\ Scheduled} * 100 \qquad (2)$$

3.2 Execution

The sortie generation process is the cycle of inspection, service, flight and maintenance used to maintain a viable Air Force Wing. The requirements for maintenance and the sortie generation process are found in AFI21-101 (2002). It is described generally in Figure 4.

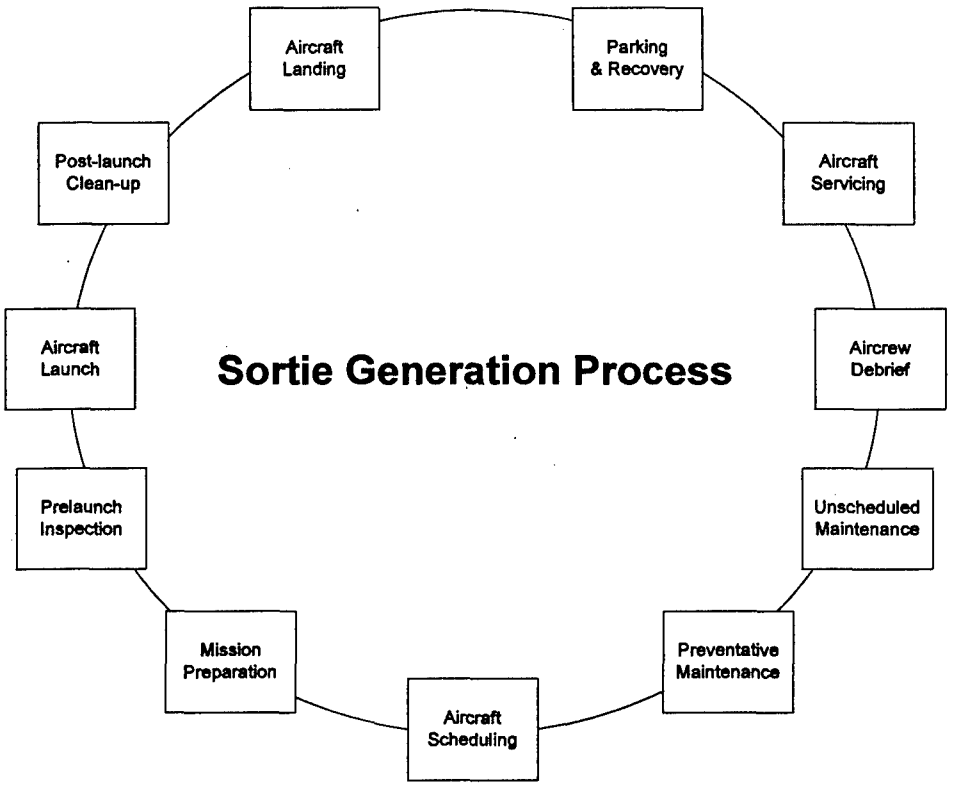

Figure 4: Sortie Generation Process (Adapted from Faas, 2003)

Typically the sortie generation cycle begins with the recovery of an aircraft from another mission. After proceeding to the parking location and shutdown of the engine, post-flight servicing is conducted. During this time the aircrew debriefs the maintenance crew on any discrepancies which are then discussed, documented, and recorded in a computerized information system, the Core Automated Maintenance System (CAMS). *Aircraft and equipment readiness is the maintenance mission. The maintenance function ensures aircraft and equipment are safe serviceable, and properly configured to meet mission needs* (AFI21-101,

2002). To prepare the aircraft for the next mission, several routine maintenance functions are necessary. Flight line maintenance includes processes to inspect, service, and maintain the aircraft. During the aircrew debriefing, the maintenance personnel are looking for both current faults and repeat faults. If a fault is confirmed through testing or inspection, a maintenance crew heads to the aircraft to conduct a repair to return the aircraft to mission-capable status. Currently, some aircrews report the aircraft status over the radio or "squawk" discrepancies back to the ground crew which gives them a head start on the repair process. *The current Air Force logistics operations system is reactive in nature, meaning that after the aircraft detects a part failure, the maintenance person must perform fault isolation procedures and then steps are taken to repair or replace the faulty item. This process is usually started when the aircraft detects a fault, which sets a flag and sends a notice to the pilot. Depending on the severity of the fault the mission can continue and the information is saved for the maintenance debrief* (Faas, 2003). The aircraft are prepared for flight by the ground crews, the pilots load the assigned mission, take-off, perform the mission and land to complete the cycle.

The impetus of the sortie generation process is the sortie schedule. The changing availability of the aircraft due to maintenance, access to personnel and the demands of operations cause the sortie schedule to evolve through re-examination and alteration at regular quarterly, monthly, weekly and daily intervals. Meetings are held between operations and maintenance schedulers to negotiate and confirm the sortie schedule (Howard and Zaloom, 1980). The sortie schedule is contrasted against the yearly plan of preventative scheduled maintenance, periodic inspections, Time Compliance Order installations, system calibrations or Time Change Item replacements (critical parts replaced or repaired based on accumulated flight hours, not based on part condition). The quarterly sortie schedule consists of a forecast of mission requirements (i.e.

configuration, needed munitions and ordnance) provided by operations to the maintenance schedulers. The monthly schedule tentatively assigns specific aircraft to specific sorties. Weekly planning involves assigning takeoff and landing times for a given sortie and rescheduling aircraft due to constraints that arise as the mission requirements solidify (i.e. sortie duration, aircraft configuration, etc) or as an aircraft becomes non-mission capable (i.e. unscheduled maintenance, phase inspection, etc).

One of the key maintenance schedulers is the Squadron Production Supervisor (Pro Super). The weekly matching of aircraft to sorties is a key responsibility of the Pro Super (AFI21-101, 2002). The weekly meeting of maintenance schedulers is a time used to review maintenance progress of a given aircraft through the flow of preventative or unscheduled maintenance. The Phase Flow is a term used to describe the regular maintenance and inspection on aircraft performed in accordance with their engineered lifecycle. There is a tradeoff of accumulated flight hours that trigger the required maintenance (i.e. Time Change Item replacements) specified in the Phase Flow and the hours needed to complete sorties. A Pro Super wants to maximize the amount of sortie hours he can use an aircraft before he loses it to the phase inspection and/or preventative maintenance.

4 User Interaction

The goal of this research is to show that simulation can be used as a tool to assist in decision making at the unit level. To make simulation useful at this level, it is important to take into consideration the users and their interaction with the simulation. In the following sections, we review the literature on user interaction, examine the ways in which users interface with simulation models and describe how we evaluated the user interface metaphor or prototype.

We start with some definitions. The Association for Computing Machinery Special Interest Group on Computer-Human Interaction (ACM SIGCHI) in 1992 defined human-computer interaction in this way:

> "Human-computer interaction is a discipline concerned with the design, evaluation and implementation of interactive computing systems for human use and with the study of major phenomena surrounding them."

In the mind of the user, the interface is synonymous with the system (Hix and Hartson, 1993). In fact, Larson (1992) writes the interface is *often the single most important factor in determining the success of a system.* Yet the interface is just one part of the whole experience a user has with the system. The user experience aims to maximize ease of learning and memorability, efficiency of use, and subjective satisfaction while minimizing error frequency and severity in the application (Padilla, 2004). Benyon and Murray (1988) differentiate between human-computer interaction and human-computer interface. Interaction includes all aspects of the environment such as the working practices, office layout, provision of help and guidance and so on. The interface is the part of a system with which the user comes into contact physically, perceptually, or cognitively. For our purposes, the user experience will refer to way in which the decision-maker interacts with the user interface (UI) and the actions the decision-maker must take to work through the problem the simulation is helping to solve for example the data input and the output analysis.

4.1 Decision Support Tools

The user interface metaphor we chose to purse is often referred to as a decision support system. First coined by Keen and Scott Morton (1978), a decision-support system (DSS) is any interactive system that is specifically designed to improve decision making of its users by

extending the user's cognitive decision-making abilities (Zachary and Ryder, 1997). The system can take many forms ranging from a simple table to elaborate expert systems. For military applications of DSS, see research done by Buede and Bresnick (1992), Schraagen (1997) and Waag and Bell (1997). Traditionally, decision support systems fall within two distinct design viewpoints.

4.1.1 Cognitive Prosthesis

A cognitive prosthesis or vehicle decision support, tries to reduce poor decisions by eliminating the defective or inconsistent decision making of a person by replacing the decision-maker with some type of algorithm. Some examples in this category are analytical hierarchy process (Tversky, 1972) and multi-attribute utility theory (Keeney and Raiffa, 1976). The cognitive prosthesis approach is often used for routine situations where decision consistency is more important than the selection of the most appropriate response under unusual circumstances. This method assumes that the decision follows a normative model. That is to say that decision making is rational and when provided with values (costs or benefits) associated with different exhaustive choices, mathematical models can be applied to those values, yielding the optimal choice that would maximize these values or minimize their costs. The cognitive prosthesis approach proposes and imposes specific methodologies to the decision maker. It delivers strong guidance at the cost of flexibility.

4.1.2 Cognitive Toolbox

The other traditional perspective referred to as a cognitive toolbox which aims to support adaptive human decision making by providing supportive instruments rather than replace the decision maker. As the name implies, this could be a toolbox of modeling languages, statistical functions, graphing packages and simulation or optimization functions. An example of this

approach would be a spreadsheet application like MS Excel. This technique is not associated with any normative model of decision making. The primary objective of this technique is to provide a set of tools that decision makers can employ in structuring, representing and exploring their problems. This approach provides a general flexibility in that it enables users to employ a variety of approaches and tools for their problem, but they provide little guidance on both problem representation and exploration.

4.1.3 Conversational Framework

Our research focuses on yet another alternative philosophy that is starting to take shape in the literature. This philosophy is often referred to as the conversational framework (Figure 5) for decision support. In this metaphor the decision-maker interacts with an autonomous system module or stimulus agent in which different kinds of knowledge sources can be encapsulated (Angehrn, 1993), for example the rules and methodologies of the sortie generation process. The stimulus agent can then be invoked to advise, inform, and criticize the user along the whole decision-making process. This approach is rooted in the assumption that decision support can be provided by facilitating and stimulating reflective learning. Facilitating reflective learning consists of enabling decision makers to incrementally give expression to their views on the decision at hand and to experiment with possible solutions. This experimentation allows the user to create alternative viewpoints and insight into the decision. The approach allows a more transparent decision process than the cognitive prosthesis and a more guided process than the cognitive tool.

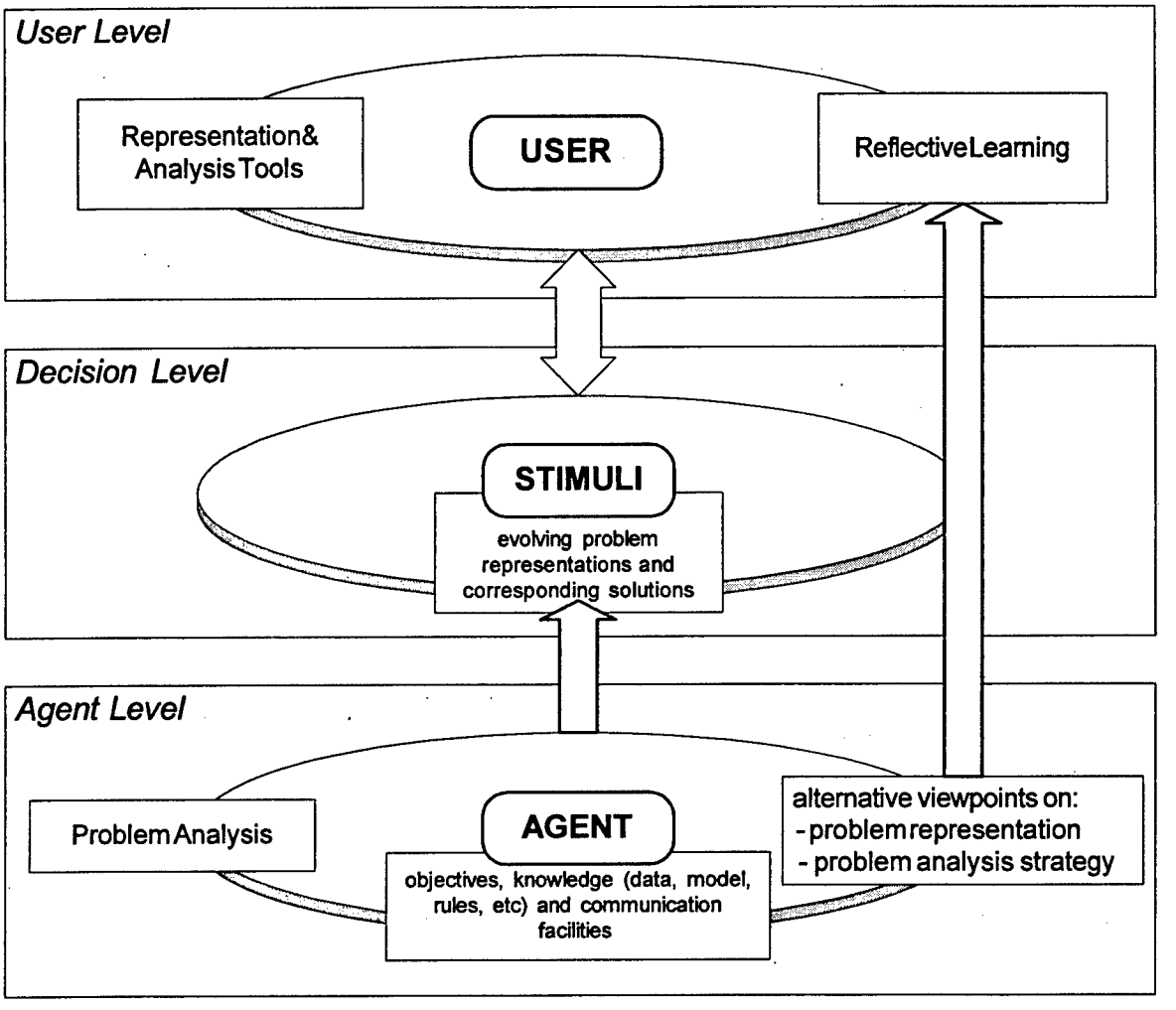

Figure 5: The Conversational Framework (Adapted from Angehrn, 1993)

4.1.4 Review UI Issues in Simulation

A simulation model can help people evaluate their current working hypothesis, goals, and plans (Roth, 1994). It can also show information related to alternative actions such as resource requirements, assumptions and required configurations (Rouse and Valusek, 1993). The military is a big user of discrete event simulation models and its analysts rely heavily upon models to gain insight into the wide range of issues facing the military (Hill et al, 2001). Based on these facts, we were quite comfortable that our users would themselves be comfortable with idea of a simulation as a stimulus agent.

Simulation by itself however presents some UI pitfalls. In terms of human computer interaction, many studies focus in on animation as the primary tool for relating information from the simulation back to the user (Aiken et al, 1990). These so-called visual interactive simulation (VIS) systems are becoming more popular due mainly to fact animation software is more affordable and the quality of the output has increased dramatically (Carpenter el al, 1993). Kuljis (1996) argues that the *VIS includes better validation, increased credibility (and hence model acceptance), better communication between modeler and client, incorporation of the decision maker into the model via interaction, and learning via playing with the VIS.* The author admits there is little empirical evidence to support these claims. Law and Kelton (2000) note that animation can aid in enhancing a model's credibility and this fact alone accounts for its expanding use; a credible model, writes Sargent (1999), is a model that decision makers are willing to use because they have confidence in the model's results. Supported by base visits and user questionnaires, we knew a key requirement of the application would be time. Meaning, this decision was made quickly and the DSS could not hinder that process. Sitting through an animation of the simulation would prove to be too costly.

Simulation projects tend to be data-driven and not necessarily user-driven. Ironically, most of the papers on simulation systems only briefly mention the data input capabilities of the systems, if at all (Kuljis, 1996). According to user questionnaires, most of the work that is devoted to creating the sortie schedule was being done in a spreadsheet application. In order for the simulation model to work effectively, it needs real time data from the user, for example, the sortie schedule and aircraft availability. Yet we did not want to add more time to the decision process by forcing the user to manually input several values before running the stimulus agent.

4.1.5 Peer Review of DSS

To get a better picture of how other applications deal with the issues, we took some time to review some peer applications. A literature reveals there are several domain specific tools that have been developed and deployed. One such example is Eagle View (Zahn and Renken, 1997) which is a prototype decision analysis tool that aids wing commanders make deployment decisions based on current state of the base based on status of planes, supplies and manpower. The Sortie Generation Rate Model (Harris, 2002) aids WG Commanders in estimating number of sorties that can be flown daily given fixed input parameters to aid in maximizing utilization rates. VMetric is a commercial application that incorporates VARI-METRIC mathematical model to aid commercial airlines in logistics decisions (Sherbrooke, 1986). The Scalable Integration Model for Objective Resource Capability Evaluations (SIMFORCE) was built by the Kelley Logistics Support Services to provide wing level maintenance managers a decision support tool for conducting what-if problems. McGee, et al (2004) developed a simulation-based model that was constructed for the (USAF) MIME repairable parts system. The authors suggest that *through the development of simulation-based models, these limiting assumptions can be relaxed, providing a model that captures more of the subtlety and variation of the system.* This model explores the privatization of the transportation practices and their effects the USAF's supply chain management. Since this model was developed just to experiment with transportation practices, many aspects of the Sortie Generation Process were ignored or simplified in the model design.

4.2 Development of User Interface

This section of the report presents the step-by-step procedure used to create the user interface. We knew that we would have limited access to active production supervisors. There are a small

number of production supervisors in the country which at the time of the research had been dwindled slightly due to deployment in combat missions. To help develop a user-centered product we decided to adopt a scenario-based design strategy. Introduced by Carroll (2000), this methodology focuses on the creation of day-in-the-life scenarios which characterize what happens when users perform typical tasks. The idea of scenario-based design has recently gained in popularity (Rosson and Carroll 2002; Nardi 1992; Sonderegger, Manning, Charron & Roshon, 2000). The approach encourages user involvement in system design, provides a shared vocabulary among the people participating in the system development project, envisions the uncertain future tasks of the system users, and enhances ease of developing instructional materials. Furthermore it provides a good brainstorming tool for planning and allows the stakeholders to consider alternative choices in decision-making.

4.2.1 Scenario-based Design (Figure 6)

Scenarios illustrate how a person's experiences and actions unfold in specific contexts or situations. They also can highlight interactions (with computer systems, people, business entities, etc.), decision processes, activity sequences, influencing factors and so forth. They may also illustrate the different ways in which varied groups or types of people experience and navigate through similar situations.

Analysis of scenarios can foster the identification of areas of difficulty (pain points) and experiential gaps (or opportunities) that may be addressed or enhanced through technology solutions. When integrated with personas, they can illustrate how different target audiences navigate through the same situation, which in turn can suggest ways in which solutions can and should be adapted for varying target audiences. Scenarios can serve as a dynamic reminder of the broad range of contexts and situations in which people may engage an interaction with

technology solutions, fostering thoughtful discussions about how to design solutions that fit into and complement or enhance people's lives.

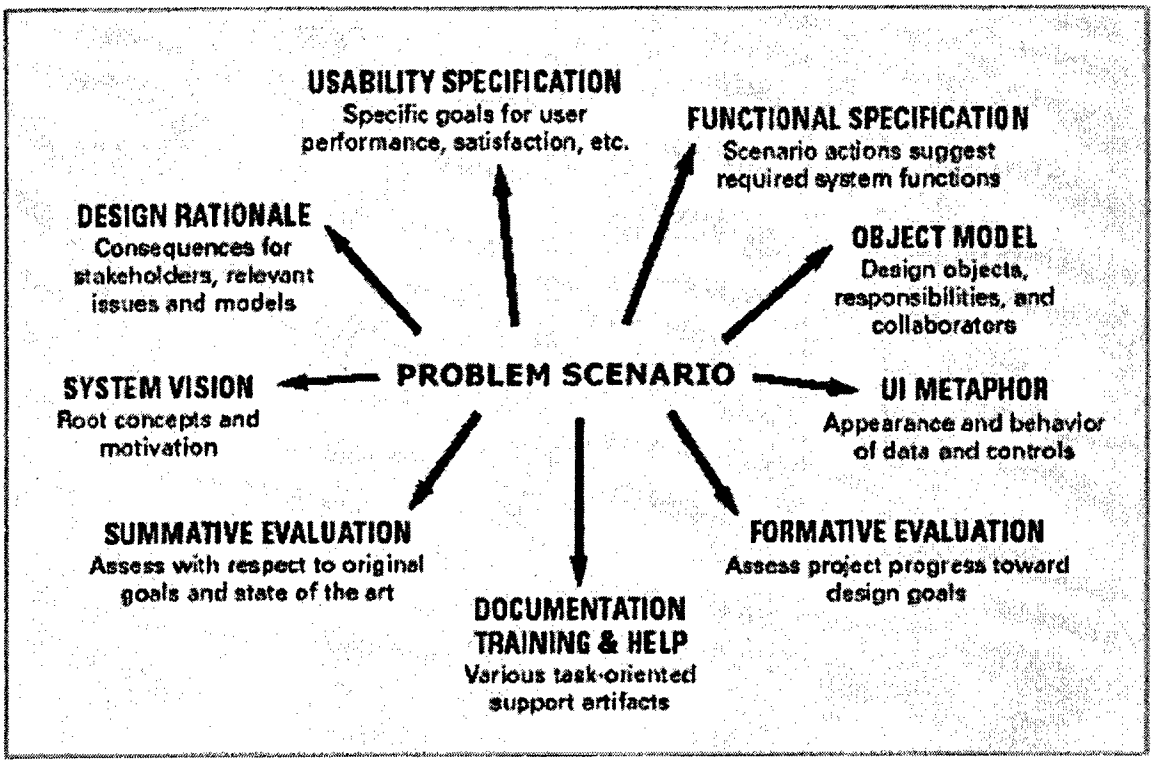

Figure 6: Scenario-based design (Adapted from Go and Carroll, 2004)

4.2.2 Design Rationale

The purpose of decision analysis is to help a decision maker think systematically about complex problems and to improve the quality of the resulting decisions. Typically this is a task in which 1) a person must select from a number of alternatives; 2) there is some amount of information available with respect to the alternative; 3) the decision timeframe is relatively long (i.e. longer than a second); 4) the choice of alternatives incorporates some uncertainty which means the best option is not necessarily apparent (Wickens et al, 2004). The process of decision making can be generally represented in three phases. In the first phase, one acquires and perceives information or cues relevant for the decision. Secondly, one begins to generate and then select hypotheses or situation assessments about what the cues mean, regarding the current and future state relevant to

the decision. Finally, one selects the alternative to take, on the basis of the inferred state and the costs or values of different outcomes. By definition, decision making involves risk and a good decision maker effectively assesses risks associated with each alternative (Medin and Ross, 1992).

4.2.3 Influence Diagram

To help us get a better picture of what entities are involved in the decision to change the sortie schedule and to help model the decision process, we developed an influence diagram (Figure 7). An influence diagram is a list of events and actions with arrows showing the flow of information and how the factors influence one another. An arrow leading from an event A to an event B implies that the probability of obtaining event B depends on whether event A has occurred. An arrow leading from a decision to an event implies that the probability of the event depends on the choice made at the decision stage. An arrow leading from an event to a decision implies that the decision maker knows the outcome of the event at the time the decision is made.

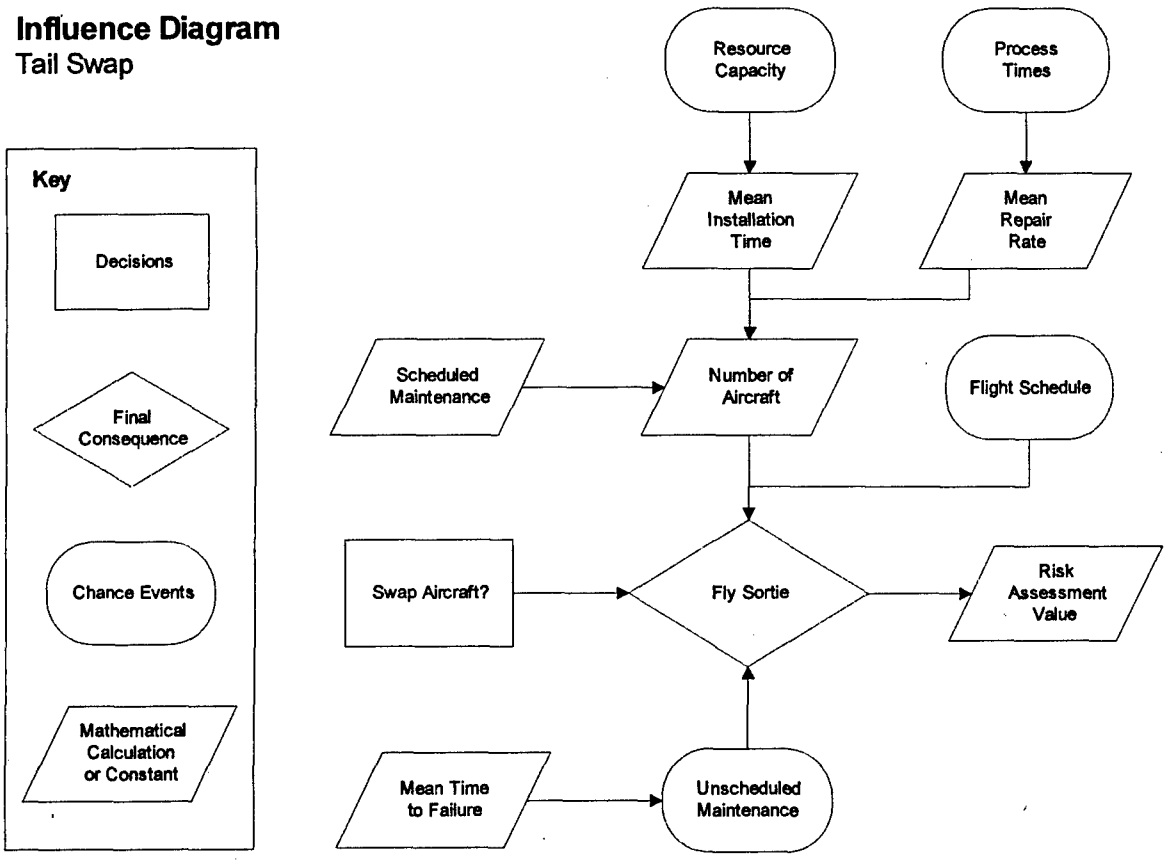

Figure 7: Influence Diagram for the Sortie Generation Process

To read the influence diagram, take for example how the simulation model uses the input for resource capacity to describe the number of personnel available, AGE available and parts available. The time it takes to replace the parts by the personnel and using required AGE is represented by the Mean Installation Time. Changes to this event could dramatically affect the number of aircraft available to the flight schedule, thus slight variations in this event could dramatically effect the decision to swap aircraft which in turn would affect the calculation of the risk assessment value.

4.2.4 Key Actors/Stakeholders

A key step in the decision analysis is the identification of the key stakeholders that influence this decision. According to AFI21-101 (2002) and interviews held with an AMU at Eglin AFB, the key stakeholders are:

Operations

Operations personnel set the flight schedule for training and combat missions. Operations personnel also assign pilots to planes. The contact meets with the Pro-Super weekly to help set the sortie schedule.

Maintenance (AMU)

- ***Commander***

  Ultimately responsible for maintenance, the commander approves the maintenance plan at all levels and ensures its execution.

- ***Production Supervisor (Pro-Super)***

  The production supervisor is responsible for the maintenance execution down to the job level. The production supervisor in conjunction with the Commander and Operations is ultimately responsible for the weekly flight schedule. The Pro-Super's job is to prioritize the AMU's resources in order to execute the daily maintenance plan and flying schedule.

- ***Maintenance Crew Chief***

  The maintenance crew chief oversees the physical hands that execute repairs on the aircraft. The crew chief is assigned to a specific plane and is extremely familiar with the nuances of its maintenance.

Though there are several stakeholders in the decision, this research and therefore the DSS requirements will only focus on the production supervisor.

4.2.5 Baseline Scenario

The focus of this research is the development of the weekly schedule as drafted by the production supervisor. The baseline scenario was developed using background information and process descriptions gathered during interviews and questionnaires. MSgt. MacNeece is not a real individual, but rather he is aggregated from the data of several real production supervisors.

> To prepare for the morning meeting, MSgt. MacNeece likes to take the monthly plan and review what needs to happen. He transposes this information into MS Excel. Then he logs into TASAMS to check the aircraft availability and weekly schedule of maintenance. To get a better picture of the bottlenecks that might affect the maintenance schedule, he checks the availability of resources (i.e. AGE, wash house, paint barn) and calls a few maintenance chiefs to gauge the

availability of personnel. He does a quick sweep of the aircraft available for load training to make sure the information is fresh in his mind. He goes back into Excel and selects the cells that contain the tail number of the planes he has available; he bolds the numbers to make the numbers stand out. He does a quick calculation of the current wing phase flow and checks TASAMS again for the current cannibalization rate.

The scenario was then used to identify key attributes of the DSS requirements and elements of the UI. For example, the use of MS Excel would imply a comfort in the Windows graphical user interface therefore UI standards developed from this preexisting familiarity should be the baseline for our interface development. Secondly, the production supervisor must view information from several different sources (i.e. TASAMS, monthly plan) therefore a core requirement may need to be some kind of data import to help combat the information overload.

4.2.6 Personas

To gain further insight into are potential users, interviews were conducted during a base visit to Eglin AFB. Questionnaires were also sent out to three additional production supervisors. Their backgrounds and means of drafting the weekly schedule were surveyed. They were aggregated together to form an archetypal user or persona. Personas are fictional people that are used to aid in the design of products and software (Table 1). The term "persona" was introduced by Alan Cooper (1999). Cooper describes a scenario as "a concise description of a persona using a software-based product to achieve a goal." Prior to Cooper, others promoted the use of abstract representations of users to guide design: user profiles and scenarios derived from contextual inquiry and user classes fleshed out into "user archetypes" (Beyer and Holtzblatt, 1998; Bloomberg, Burrel, and Guest, 2003; Hackos and Redish, 1998). Personas used alone can aid design, but they can be more powerful if used to complement, not replace, a full range of quantitative and qualitative methods (Pruitt and Grudin, 2003).

Table 1: Persona Definition

Background
MSgt. MacNeece has been in the AF for 21 years. In that time he has worked in many positions in the AMU. He knows his job well and the jobs of the men who serve under him. He prides himself on the time he spends planning maintenance to keep the AMU a well running and well oil machine.

Quick Stats

Age: 39

Education: High School Diploma

Skill Level: 9

Computer Interest:
Interested in computers in general enjoys using them

Computer Experience:
Modest, not an expert but knows how to use the tools he needs

Key Insights

Drafting the Weekly Schedule
MSgt. MacNeece likes to take the monthly plan and review what needs to happen. He transposes this information into MS Excel. Then he logs into TASAMS to see check the aircraft availability and weekly schedule of maintenance. To get a better picture of the bottlenecks that might affect the maintenance schedule he checks the availability of resources (i.e. AGE, wash rack, paint barn). He does a quick sweep of the aircraft available for load training to make sure it is fresh in his mind. He bolds the tail numbers of the planes he has available and does a quick calculation of the current wing phase flow and checks in TASAMS on his current cannibalization rate.

Accessing Risk
The initial calculation of the phase flow looks to be about 5 points higher than MSgt. MacNeece is used to seeing. To help gauge why the phase flow is spiking this week he exports wing data from TASAMS and imports it into MS Excel. He walks through the wizard that pops up on the screen and adjusts the installation mean time up slightly to account for the staff shortage in the wash rack. The output report shows that he should expect about 8 opportunities for change, which is about 4 more than he had been expecting.

4.3 System Vision

After having identified the users and the decisions they must make, the next step was to lay out our vision of how the system should look and operate. This section gives a review of the system architecture, human-computer interaction, and basic components of the user interface metaphor.

4.3.1 System Architecture

The three tier architecture (Figure 8) is a popular choice for web-based applications and net-centric information systems because of the increased performance, flexibility, maintainability, reusability, and scalability. It hides the complexity of distributed processing from the user. The data layer provides database management functionality and is dedicated to data and file services that can be optimized without using any proprietary database management system languages. The data management component ensures that the data is consistent throughout the distributed environment through the use of features such as data locking, consistency, and replication. It should be noted that connectivity between tiers can be dynamically changed depending upon the user's request for data and services. The business tier provides process management services (such as process development, process enactment and process monitoring) that can be shared by multiple applications. Our DSS has three basic components, the input analyzer, the simulation model and the output analyzer. The presentation layer provides the user interface to these two tiers without being directly tied to the data structure or the process management services. Thus the interface and the data are stored separately from the simulation model itself. Therefore the interface can be altered without adverse effects to the model or the underlying data structure.

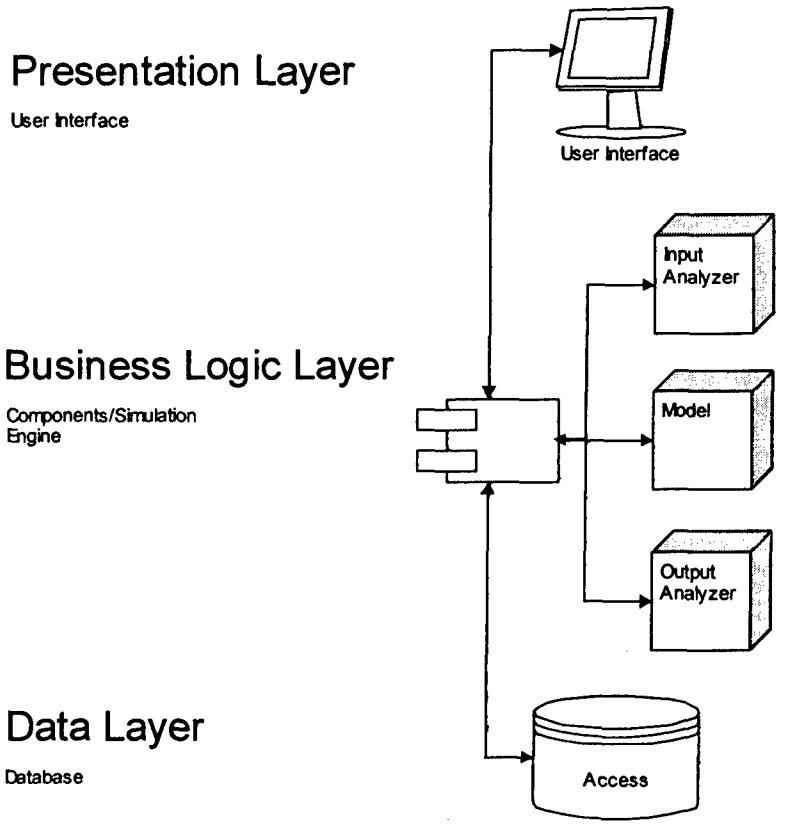

Figure 8: Sortie Generation Tool Structure

4.3.2 Agent Interaction

The user will interact with the system in two cycles (Figure 9). The first cycle will capture basic data inputs and present the user with potential change opportunities in the schedule. These opportunities are times within the simulation when a plane needs to be swapped out of the weekly schedule due to some random circumstance such as unscheduled maintenance. The user will also be presented with a risk gauge, which is the calculation of variance across the simulation run. This number can be used to help get a sense of how metrics such as utilization and aircraft availability might be affected by the swaps suggested in the simulation model. If risk is high, the decision maker can go through a second cycle. In this phase of the decision process the user can tweak the values for installation time or resource capacity to see if variations in those numbers might affect the number of change opportunities.

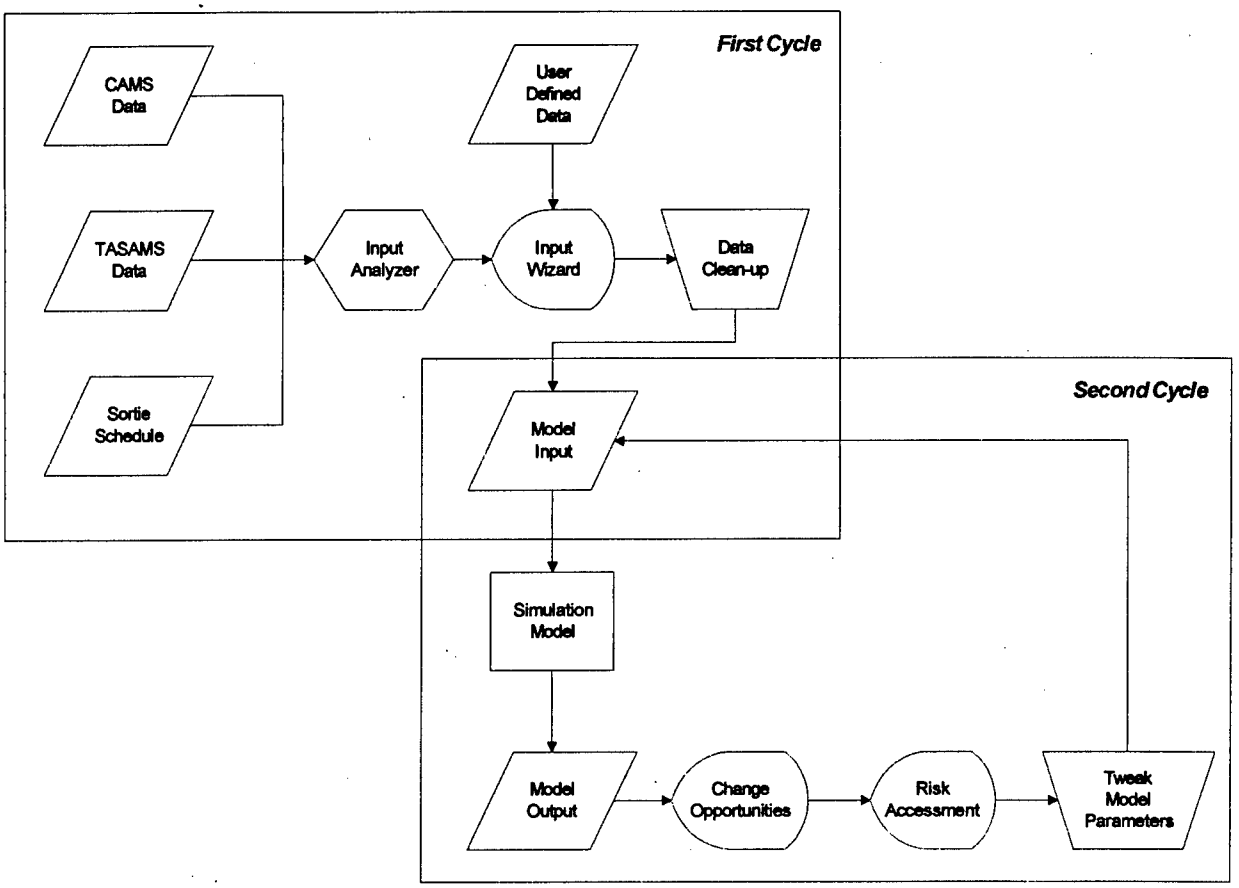

Figure 9: Diagram of the DSS Cycle

4.3.3 Functional Requirements

To help guide the interface development process, we turned to the baseline scenario to create four core functional requirements that would guide the user interface metaphor. These requirements represent the pain points or those areas which are the most problematic in the decision process. Many of the points listed below piggy back off of the design heuristics which will be describe in a later section.

- **Reduce Information Overload**

  The weekly schedule is generated using several data sources (i.e. TASAMS, CAMS, monthly plan, crew input) yet there is currently no means to view all this information

in an aggregate form. For a weekly schedule, this could many lines of data. The system should aid in data aggregation.

- **Sensitivity to Resource Limitations**

  Due to budget restrictions and aging aircraft parts and personnel are often in short supply. As resources are reduced the aircraft availability is reduced. The system should suggest new ways to work within these constraints.

- **Aid the Evaluation of Multiple Schedules**

  Due to the overhead needed to generate a schedule, it is difficult to evaluate multiple schedules against available resources. They systems should allow the user to quickly manipulate potential schedule and resources.

- **Sensitivity to Time Constraints**

  As with any project, timing is crucial. The DSS should not dramatically increase the time it takes to generate and test draft sortie schedules.

5 Modeling Approaches

Once the data handling system gathers the needed inputs, they must be supplied to a simulation model which will provide the output data. This section of the report will describe our modeling methodology. In our previous research we stated that simulation was used to allow the development of a model that is more complete, flexible, and expandable. In this research we take advantage of the expandability of a simulation model. In the following sections we complete a brief review of our previous model and continue on to provide a detailed description of our model expansions.

5.1 Simulation Model

A baseline model was developed for our previous research in Arena © 7.0 to simulate the current

MIME supply chain for the weapon system being studied. This baseline model was used to compare various commercial logistic practices that potentially could be adopted by the Air Force to improve supply chain efficiencies. In our expanded model the supply chain portion of the model is used to support the new sortie generation logic.

It was important to the accuracy of our results that our model be a close representation of the current repairable parts supply chain system. Throughout the modeling process, both during our previous research and in the development of model expansions, we communicated with our contacts at the Air Force. We both received process data from them as well as provided them with validation statistics and model data. We also visited Eglin Air Force base to conduct interviews with maintenance officers and get a firsthand look at the flight line in operation. This open line of communication allowed us to gain a full understanding of the system we were modeling. Appendix 1 contains a list of all model inputs along with their distributions and parameters which were developed for our previous research. The data provided supplied in Appendix 1 was developed in coordination with the Air Force and verified through our contacts.

5.1.1 Supply Chain Structure

In the baseline example model, there are six independent bases supported by a single depot. There are twenty-four aircraft assigned to each unit, three units assigned to each squadron, and one squadron assigned to each base. In this structure, there are a total of 72 aircraft assigned to each base. This results in a total of 432 aircraft within the system. In our current research we are only interested in evaluating the performance of a specific number of aircraft at a specific base, but the other bases and aircraft are important to simulate competition for parts throughout the system. The six bases are split into two regions, with three bases in each region. Figure 10

details the structure for the baseline model. In the figure, we have illustrated the squadron, unit, and aircraft for Base 1. The other bases have a similar structure.

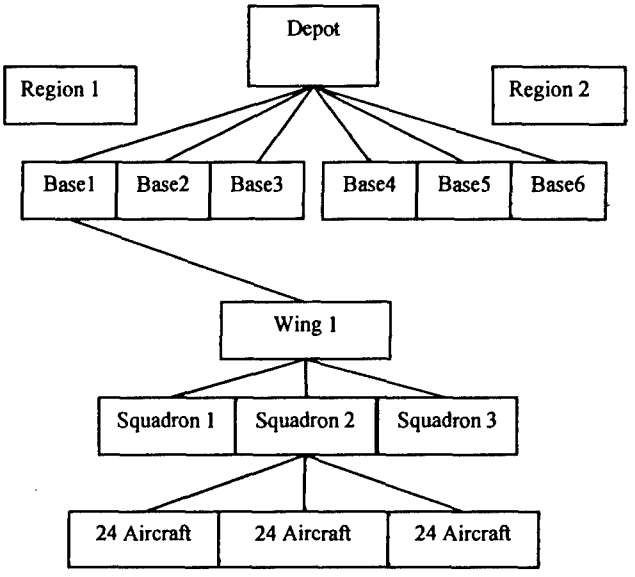

Figure 10: Supply Chain Structure

5.1.2 Weapon Systems and Bases

The baseline model represents weapon systems (for the purposes of this research, an aircraft) as objects with two levels of indenture. Initially, each aircraft is assigned a base number, index number, and tail number. The index number is a model-wide unique number assigned to each aircraft. This number allows the user to compare aircraft individually across bases. The tail number is unique to each aircraft at a given base. The base number indicates the base at which the aircraft is stationed. The model can accommodate a variable number of bases, and each base can have a variable number of aircraft (both values are set by the user

Each weapon system has two levels of indentures. The first level of indenture entails aircraft which are made up of multiple LRUs. These LRUs are in turn comprised of multiple SRUs constituting the second level of indenture. The number of SRUs per LRU type can vary as set by the user; however, the number of LRUs per aircraft remains constant system wide. In the baseline model there are six individual LRU types. Each of the 432 aircraft in the system is comprised of six LRUs, one of each type. LRUs of the same type are identical and interchangeable.

The number of SRUs per LRU can vary per LRU type and is set by the user. . The SRU types for each LRU type are unique and cannot be shared between LRU types, but within the same LRU type, the component SRUs are identical. In the baseline model each of the six LRU types are comprised of four SRUs yielding a total of 24 SRUs per aircraft.

5.1.3 Weapon Status

In our model, as stated earlier, the weapon system we are dealing with is an aircraft. For the purposes of this model, aircraft are always categorized as being in one of three states:

(i) Mission Capable (MC). An aircraft is designated MC when it is capable of flying a sortie. This status can correspond to an aircraft that is currently flying a sortie or is waiting to be assigned to a sortie.

(ii) Non-Mission Capable (NMC). An aircraft is designated NMC when one or more of its critical SRUs fails. This status corresponds to an aircraft that is down either awaiting a spare part or currently in the process of spare part installation. NMC aircraft cannot fly sorties.

(iii) Phase Inspection (PI). An aircraft is designated PI when it enters the phase inspection module. While in phase inspection the aircraft is not available to fly sorties; however, the

aircraft is not listed as NMC because phase inspection is a scheduled maintenance operation.

The percentage of time each aircraft is in each state is tracked and reported as a key performance metric of the simulation model. In further studies the number of weapon system states could be expanded to include states such as Partially Mission Capable, Cannibalization, etc.

5.1.4 Failures

The failure of an SRU results in the failure of an LRU and therefore the weapon system. While on the aircraft, SRUs are modeled as entries in a 2-dimensional array. Each cell of the TTF matrix contains the time to failure (TTF) for the SRU corresponding to that cell. This value is generated by a distribution held in the expression array "mean-time-to-failure" (MTTF). Each cell of the MTTF expression array contains the distribution used to generate the TTF for the SRU corresponding to that cell. Currently, the baseline model contains three levels of MTTF (in hours), each of which is modeled as an exponential distribution with some mean value: high-exponential (500), medium-exponential (400), and low-exponential (300). There are eight SRUs assigned to each of these three levels.

While an aircraft is operational it accrues operating hours, and each cell corresponding to that aircraft in the TTF array (i.e. every cell representing a component SRU for that aircraft) is decremented equivalently. Aircraft failure occurs when any of the component SRU cells equals or drops below zero.

5.1.5 Sortie Assignments

In our previous research sorties were simply assigned in a random fashion to available planes. This research concentrates on the sortie generation process; therefore, a significant amount of detail was added to the sortie assignment process. Sorties for a specific number of aircraft

determined by the user will be run on a daily basis from a schedule that is provided by the user. The schedule includes the tail number, takeoff time, landing time, and configuration required for each sortie as described in the section describing user inputs. At the beginning of each day a logic entity is created that examines the schedule and creates all of the sortie entities for the day. The sortie entities will have the following attributes: tail number, time until release, takeoff time, sortie length, expected landing time, and configuration. The tail number specifies which aircraft is supposed to execute the sortie. Time until takeoff (TUT) is a new term defined for this simulation, and is equal to the Takeoff time minus the current time, yielding the delay period before the sortie is scheduled to be executed. The time until release (TUR) is generated from the triangular distribution with parameters (TUT-2hr, TUT-2.5hr, TUT-3hr). The TUR gives us the delay between the current simulation time and the time at which the aircraft will be released for pre-flight operations. Expected sortie length (ESL) is defined as landing time minus takeoff time. The sortie length is generated from the triangular distribution with parameters (ESL-0.5hr, ESL, ESL+0.5hrs). Once the sortie entities have their attributes assigned, they proceed to a delay block where they are delayed the specified TUR. When the sortie is released it sends a signal to the queue holding the waiting aircraft, and the aircraft proceeds to the pre-flight operations.

5.1.6 Pre-Flight Operations

The aircraft are released for Pre-Flight well before the scheduled sortie time. In our simulation we generate this release time using the triangular distribution and store it as an attribute as described in the previous section. The first operations to be performed once the aircraft have been released for pre-flight are refueling, weapons loading, and configuration. The time required to complete the refueling and weapons loading are sampled from triangular distributions with

parameters (8, 10, 12) and (25, 30, 35) minutes respectively. If the aircraft must undergo a configuration change, the aircraft is delayed by a processing time generated from the triangular distribution with parameters (30, 45, 60) minutes. Before the aircraft proceeds to the next set of preparatory operations, the production supervisor must do an exceptional release for the aircraft. This exceptional release includes a general walk around and forms check. The time to complete the exceptional release is generated from the triangular distribution with parameters (8, 10, 15). At this point in our model, we simulate the probability that an error with the aircraft was found during the preceding operations using a Bernoulli distribution. The probability that an error was found is set to 0.005, while the probability that there were no errors is set to 0.995. If an error was found, we again use the Bernoulli distribution to model the probability that the error can be fixed before the aircraft is scheduled to fly a sortie. The probability that the error can be fixed is set to 0.50, and the probability it cannot be fixed is set to 0.50 as well. If the error cannot be fixed in the remaining time there are two alternatives: if there is a spare plane available it is inserted into the schedule, if there is not a spare plane available the sortie is cancelled. If the aircraft is error free or has been fixed in the allotted time it is deemed crew ready and moves to final preparations that include engine start, final systems check, and taxiing. The final preparation time is generated from a triangular distribution (15, 20, 25) minutes. Final preparations include crew show, dash one check, and engine start. Since the aircraft's engines are started during final preparation time, the aircraft's operating hours continue to accrue; therefore, after final preparation is completed, the total elapsed time since engine start is decremented from the TTF values associated with that aircraft.

A pre-flight check of all aircraft component SRUs is then performed. If any of the aircraft's component SRUs have failed, the failed part(s) is/are removed from the aircraft and

then sent to the repair process. The aircraft is then forced to wait for spare parts. This is called a ground abort. If a ground abort occurs, a spare is substituted, but if there is not a spare available the sortie is cancelled. If no failures are found, the aircraft flies its assigned sortie.

5.1.7 Sortie Flights

Once the aircraft has passed the pre-flight inspection, it is ready for takeoff. Before takeoff the aircraft must first taxi to the runway. The time it takes an aircraft to taxi to the runway is generated from the triangular distribution with parameters (5, 7, 10) minutes. At this point the current accrued operating hours are again decremented form the TTF matrix and each of the aircraft's parts are checked for failure. If a failure is found, the aircraft proceeds to the repair process. If there is a spare available it is substituted, and the sortie is delayed by the taxi time distribution. If there is not a spare available the sortie is cancelled. After the end of runway check, the aircraft is ready for takeoff. The time it takes for each aircraft to takeoff is generated from the triangular distribution with parameters (2, 3, 4) minutes; however, before the aircraft can takeoff it must first wait until a runway is available. After seizing a runway and taking off, the aircraft undergoes an in-flight check. If any SRUs are found to be failed, the sortie is aborted, a runway is seized, the aircraft lands, and then moves to the repair process as previously described. This is termed an air abort. If the aircraft passes the in-flight check, it continues to fly the sortie.

The sortie duration is part of the user input captured on the schedule, and is captured as an attribute as described in section 6.1.5. The aircraft is delayed by the previously calculated sortie duration. After completing the sortie, the aircraft seizes a runway and lands. Landing time in minutes is generated from a triangular distribution with parameters (14, 15, 16). Once the aircraft has landed, it undergoes its post flight check. The duration of the sortie is decremented

from all of the corresponding cells in the aircraft's TTF matrix. If any of the aircraft's SRUs are found to be failed, the failed parts are removed from the aircraft and proceed to the repair process, and then the aircraft moves to wait for spare parts. If the aircraft passes the post-flight check, it will continue on to wait for its next scheduled sortie. Aircraft will continue to fly sorties until one of the flight checks indicates that one or more of its aircrafts SRUs has failed.

5.1.8 Phase Inspections

The total operating hours for each aircraft is tracked. Once an aircraft accrues 280-320 operating hours, it must under go a phase inspection. While an aircraft is in the phase inspection process its weapon system status is set to PI. A phase inspection is a complete check of the aircraft from top to bottom. For a more complete description of our modeling of the phase inspection process please reference our previous report.

5.1.9 The Replacement Process

The model checks each SRU associated with the aircraft sequentially in each of the flight checks. The first time a cell in an aircraft's TTF matrix is less than or equal to zero, the aircraft is considered in failure. When a failed SRU is detected, the aircraft is marked as being failed, and the model removes the SRU from the aircraft. This SRU is sent to the repair process, which is described later. The model then continues to check for other SRU failures on that aircraft. Once a failed aircraft completes the flight check, the model performs an inventory check for the failed parts associated with that aircraft. Once a needed spare part is available at the base, the installation process begins. After all failed parts have been replaced on the aircraft, the aircraft is once again mission capable.

5.1.10 Repair Process

When a SRU is deemed defective, the model creates an entity representing the defective SRU. It is highly unlikely that this failed SRU can be repaired at the base (Miller 1992). In the majority of cases, the SRU must be sent to the depot for repair. If the SRU can be repaired at the base, the travel time to the repair station from local inventory is assumed to be zero and the SRU enters the queue for the base repair resource. If the SRU must be repaired at the depot, the SRU is delayed some shipping time, and then enters the queue for the depot repair resource

The repair stations at all bases and the depot give priority to backorders for repair jobs. Repair times at each base and the depot are random distributions set by the user. In the baseline model, the repair times are generated from an exponential distribution with a mean of eight hours.

If the part must be sent to the depot for repair, an order for the part is generated and sent to the depot. This order waits in the order queue at the depot as mentioned earlier. This practice holds with a one for one inventory policy. In other words, for every part that is sent to the depot an order is generated for a part to be sent back to the base, a one-for-one replenishment policy. Again in this queue, backorders are given priority.

Upon completion of the repair process, the SRU becomes functional and the part is sent to inventory. If the SRU was repaired at the base, the base inventory is incremented. If the part was repaired at the depot, the depot inventory is incremented.

5.2 Initializing the Model

The focus of the sortie generation model is the execution of a weekly schedule at the squadron level. In our previous model, we focused on modeling the supply chain. In our sortie generation model we expand our previous model to include a detailed modeling of the sortie generation

process. The supply chain and its multiple demand points model competition for parts exogenous to the sortie generation process. This competition for parts will have a direct effect on the ability of the squadron to meet a specific schedule.

In order to correctly evaluate a schedule provided by the user the model must be initialized to a current state before schedule execution. To capture a beginning state for the supply chain the model is warmed up for a 6 month period of time. This effectively spreads parts and resources throughout the supply chain giving a starting point for executing the given schedule.

In many cases the Pro. Super. has some knowledge of the state of the supply chain. That is to say they can estimate if parts are expected to move a little faster or slower during the scheduled week. This is effectively modeled by allowing the user to adjust the number of parts within the system by plus or minus 10-20% from the input screen. This also allows the user to do some what if analysis.

5.3 Initial Aircraft State

After the warm-up period has been completed, the warm-up aircraft at the experimental base are deleted from the model. At this point new aircraft are created with initial settings as defined by the user. This is one of more challenging modeling issues related to utilizing simulation technology at this level. Essentially, we must determine how to capture the beginning state of each aircraft within the squadron. From looking at Air Force documentation and observing the system we have developed the following plan for capturing the initial aircraft state.

5.3.1 Status

In this case we are using status to refer to the current condition of the aircraft, much like the reports handed out at the morning meetings between the Pro Super and expediters. To capture

aircraft status a dropdown is provided which includes different states. This dropdown is accompanied by a series of three input boxes that will be used to capture the expected delay time for those states which require the aircraft to be incapable of flying sorties. These three boxes are used as input to the triangular distribution, high value, low value, and mode. The states that are available in the dropdown are as follows:

- Mission Capable – available to fly sorties
- Phase Inspection
- Unscheduled Maintenance
- Scheduled Maintenance
- Depot Maintenance
- Cross Country
- Cannibalization
- Other

In many situations involving maintenance there will be multiple items that must be repaired. To capture this scenario, for example, there could be 5 sets of input boxes for the expected delay time. These boxes will be accompanied by an input box for the cause and a dropdown box to specify the processing order. The cause input will have no effect on the model, but will help the users track what they have entered. The processing order dropdown box will include the number 1-5, and the work delay times that are entered will be experienced according the processing order number selected for that delay. To model concurrent operations the same processing order number can be selected for multiple delays. In other words when the model is run it will process the delays for each aircraft according the processing order. If multiple delays bear the same processing order number, the longest of the delays will be experienced by the aircraft.

5.3.2 Configuration

Configuration describes the physical configuration of the aircraft. In the case, we observed at Eglin AFB that the only physical configuration concern was the tank configuration. Thus, in this proof of concept we only model this configuration under the recognition that other weapon systems and missions may require additional configuration modeling. The tank configuration is captured through a dropdown box. The tank configurations we observed are as follows:

- One Tank
- Two Fuel Tanks
- Three Fuel Tanks
- Clean

Different missions require different tank configurations as specified by the schedule. Therefore it is important to capture the initial configuration to correctly model the delay in changing configuration when needed.

5.3.3 Phase Hours

The phase flow is a major consideration taken into account when generating a schedule. It is also important for the Pro Super to know where they will stand after executing a particular schedule. Phase hours indicate the number of flying hours an aircraft must accumulate before its next phase inspection. In this regard, it is an indication of the number of hours accrued by the aircraft since its last full inspection, and therefore, it is an indication of the state of the aircraft's working parts. The phase hours for each aircraft can be captured through an input box. The Mean Time to Failure for all of the aircraft's parts can then be derived from the phase hours. To initialize the TTF matrix, the TTF for each SRU is generated as previously described, and then the accrued phase hours are subtracted from the generated TTF values.

5.4 Model Output Data

For this model to be useful, the data provided to the user in the end must be both easy to understand and interpret. For our model we have developed two metrics: deviation from 45° phase flow and number of change opportunities.

In the USAF maintenance officers are called to keep their aircraft in a continual state of readiness. One of the main measures of readiness is adherence to a 45° phase flow line. Phase flow refers a graph, across a squadron, of the number of operational hours remaining before each aircraft must undergo a phase inspection, and therefore, be out of operation for a number of days. On this graph it is important that there are not a large number of aircraft that are very close to phase inspection, and conversely it is important that there are not a large number of aircraft with just a few accumulated hours. If there are a large number of aircraft at either end of the spectrum it would mean that a large number of aircraft would come due for phase inspection at basically the same time. In essence an unbalanced phase flow could render a large portion of the squadron useless at a critical time. Maintenance managers attempt to keep an even dispersion of phase hours across the squadron. The perfect dispersion would result in a 45° line. After our model has run the user provided schedule it will output the number of phase hours for each aircraft and graph them. The percent deviation from a 45° line is then calculated and displayed as a measure of schedule performance.

There are many instances when executing a schedule in which problems will arise that can be handled by the maintenance officers in a manner which does not result in a schedule deviation. In our model, instead of trying to mimic the behavior of the maintenance staff perfectly, we keep tack of instances in which the maintenance officer would have had to interact with the schedule. We call these instances change opportunities. For example, if an error occurs

with the aircraft before exceptional release the Pro Super might tell his maintenance crew to concentrate their efforts on fixing that aircraft before it is scheduled to fly, or the error might be serious enough that a spare aircraft must take its place. In this situation, there are a number of things that might occur so for the purposes of our model any aircraft error results in a change opportunity or an opportunity for the maintenance officers to interact with the schedule.

5.5 Data Handling Approaches

In our previous model data was handled strictly through Excel. The user could change values in Excel which were then imported into the model as simulation parameters. For our current research Excel is still used as the data capturing mechanism. We felt that the end user would be most comfortable using the spreadsheet format. In our new model once the data is captured in Excel it is imported into Access and from there we bring it in to the simulation. We chose to use Access as an intermediate step because we want our model to be scalable to handle large amounts of data. For example in the future it may be useful to model a larger number and more complicated of LRUs. This would require a large amount of data for failure rates, repair times, etc. There are many instances where large amounts of data might be useful in the future and Access allows us to have the capability to handle the data efficiently.

6 Test Scenario Description

In this section we walk through the user interface developed for this tool, and then develop a schedule to test our tool. We demonstrate the usability of our tool as well as provide real results. The schedule presented below was developed from actual USAF schedules and has the complexity to test every piece of our tool.

6.1 User Interface Metaphor/Prototype

This section will describe the user interface in detail including screen shots and detailed descriptions of the inputs (Figures 11-19). Appendix 1 contains all of the inputs which were used in our previous research and are still available in this expanded model. To facilitate the core requirements, we decided the best interface metaphor is a wizard. The user is walked through the cycles of the DSS.

6.2 First Cycle

The following sections will describe the first cycle in the DSS cycle. Each of the steps is illustrated with a screenshot followed by a description of the screenshot.

6.2.1 Step One

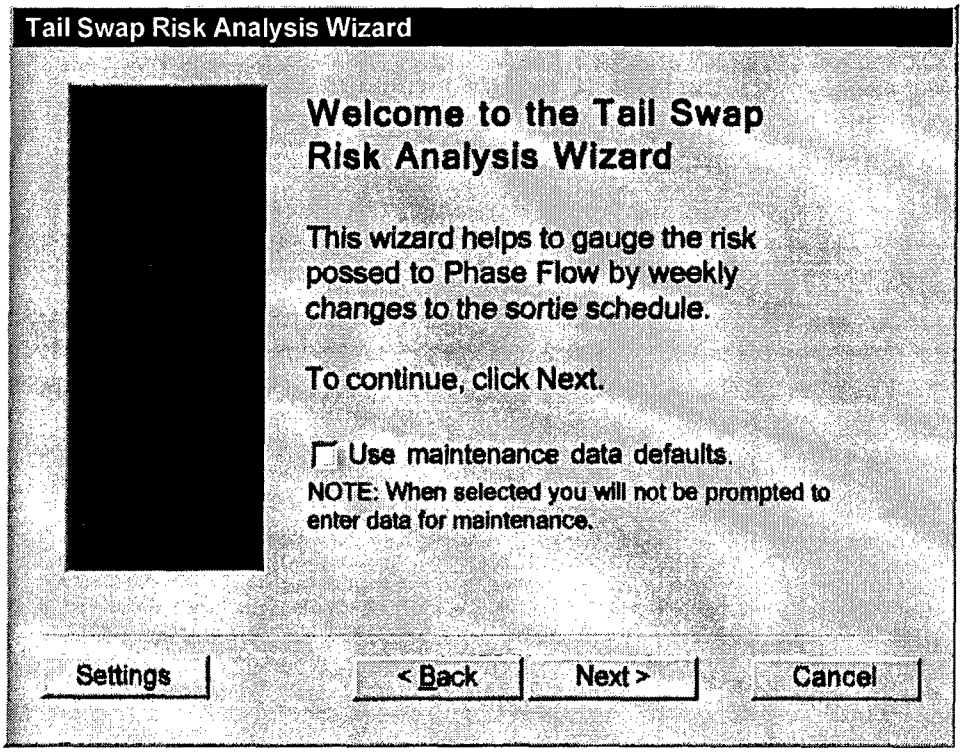

Figure 11: Welcome Screen

This screen is the wizard welcome screen and describes what the user can expect by completing the steps within the wizard. It allows the user to denote if he/she would prefer to use the

simulation models fallback distributions for the maintenance time and installation time. From the screen, the user can travel in several directions. Clicking the "SETTINGS" button will take the user to the settings window defined on the next page. Clicking "NEXT" will take the user to the sortie schedule window. Clicking "CANCEL" will close the application. "BACK" is disabled.

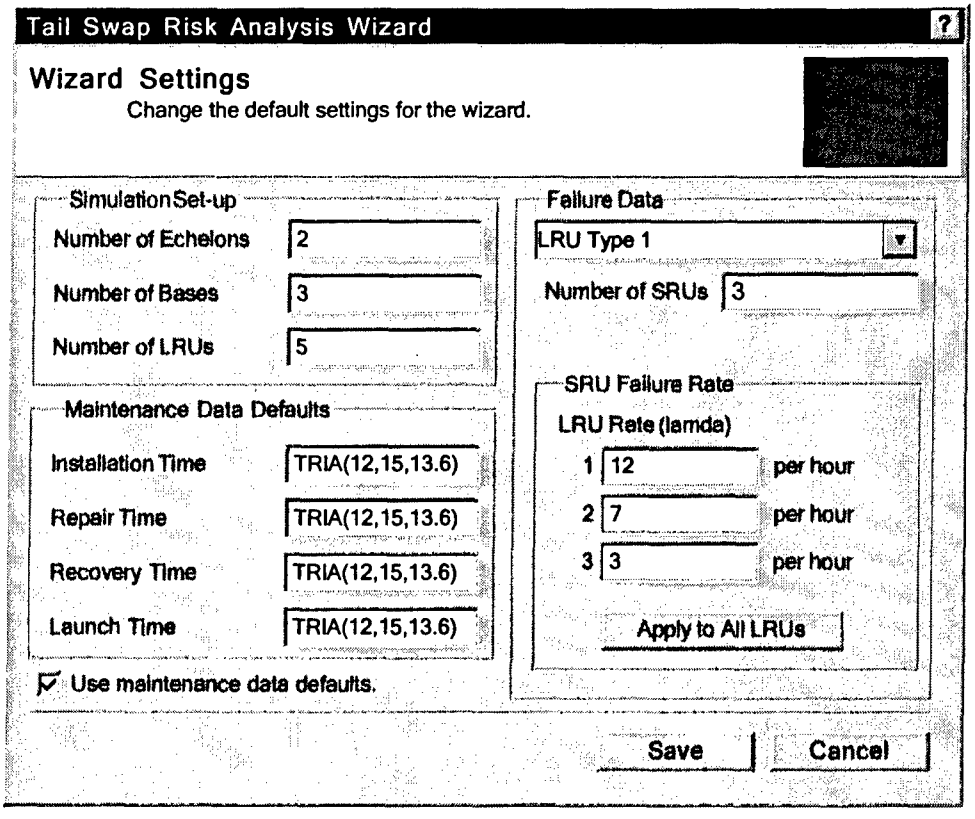

Figure 12: Wizard Settings

The "SETTINGS" button appears at the bottom left of all the wizard screens. From this menu the user can change the simulation models default settings. Once the "SAVE" button or the "CANCEL" button is clicked the user is returned to the welcome screen. Clicking "?" in the top right corner will take the user to help section.

6.2.2 *Step Two*

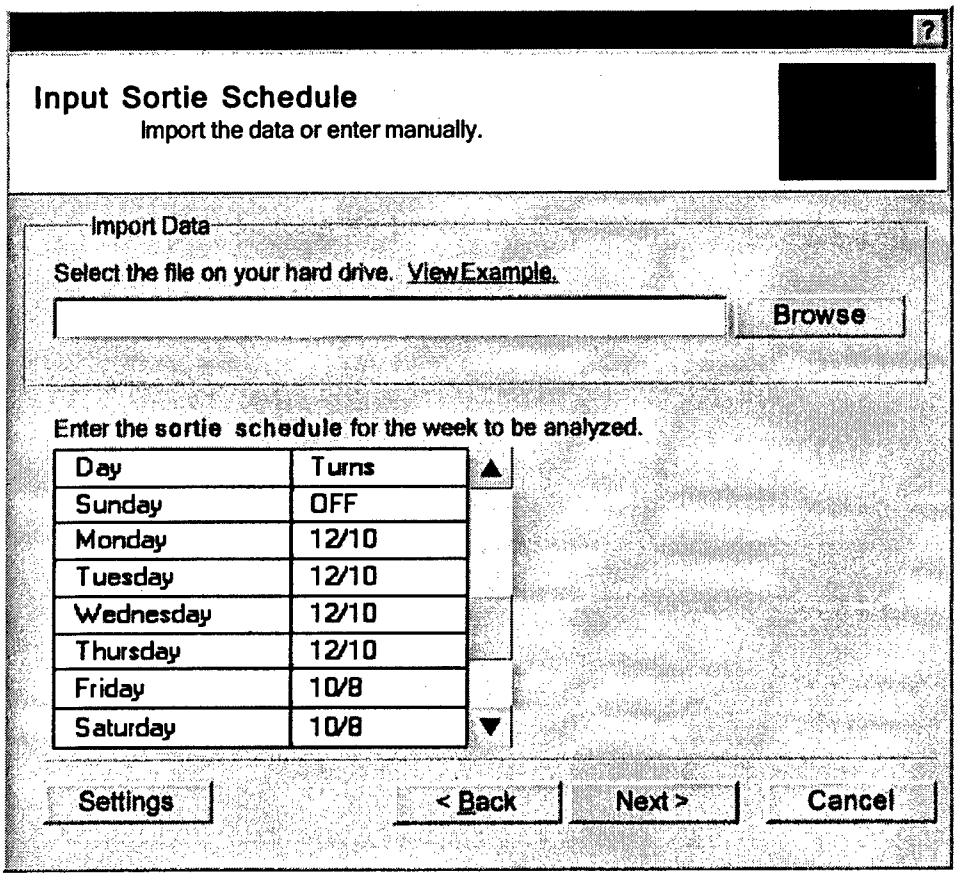

Figure 13: Input Sortie Schedule

This screen allows the user to import the sortie schedule or enter the schedule manually. If the schedule is imported the user will have the option to tweak the data once it is loaded into the wizard and displayed in the schedule text area. The DAY column refers to the day of the week on which this event will occur. The TURNS column refers to the number of aircraft to be launched in the morning/evening. Clicking the "SETTINGS" button will take the user to the settings window defined on the next page. Clicking "NEXT" will take the user to the aircraft status window. Clicking "BACK" will take the user back to the welcome screen. Clicking "CANCEL" will close the application.

6.2.3 *Step Three*

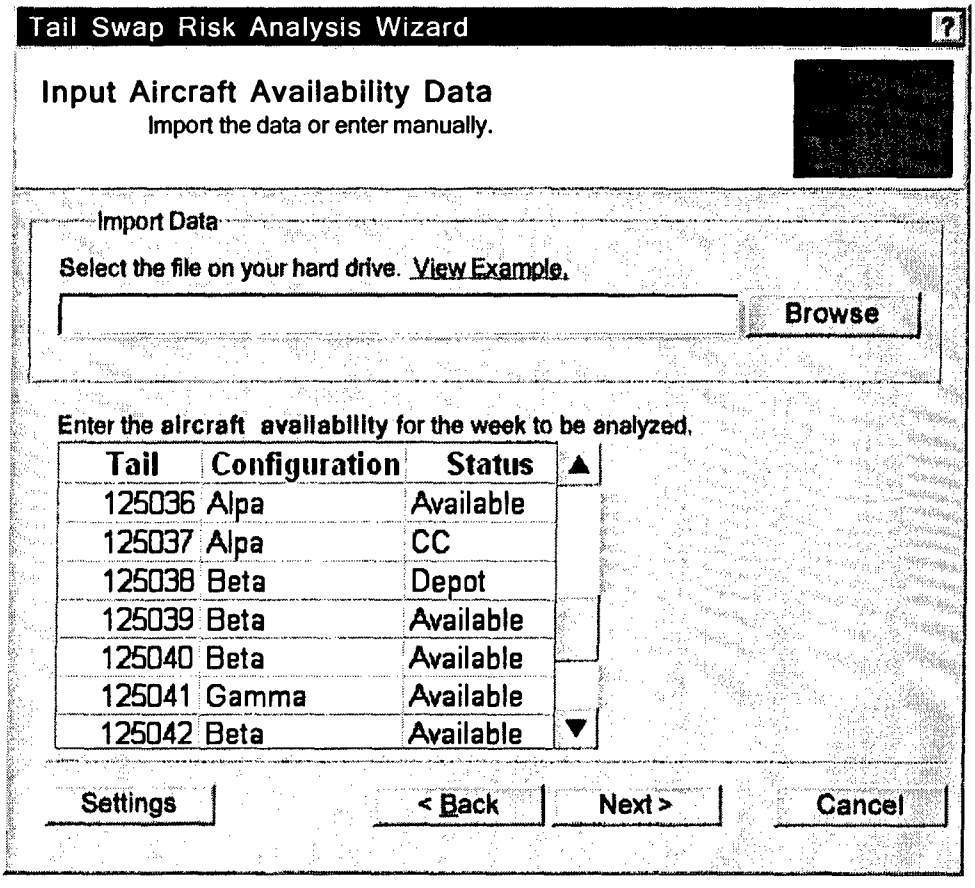

Figure 14: Input Aircraft Availability

This screen allows the user to import the aircraft availability or enter the aircraft status manually. If the aircraft status is imported the user will have the option to tweak the data once it is loaded into the wizard and displayed in the aircraft status text area. The TAIL column refers to the tail number used to identify a specific weapons system. The CONFIGURATION column refers the fuel tanks and ordnance configuration the aircraft currently equipped to accept. The STATUS column denotes if the aircraft is available to the schedule. Clicking the "SETTINGS" button will take the user to the settings window defined on the next page. Clicking "NEXT" will take the user to the maintenance data window. Clicking "BACK" will take the user back to the sortie schedule screen. Clicking "CANCEL" will close the application.

6.2.4 *Step Four*

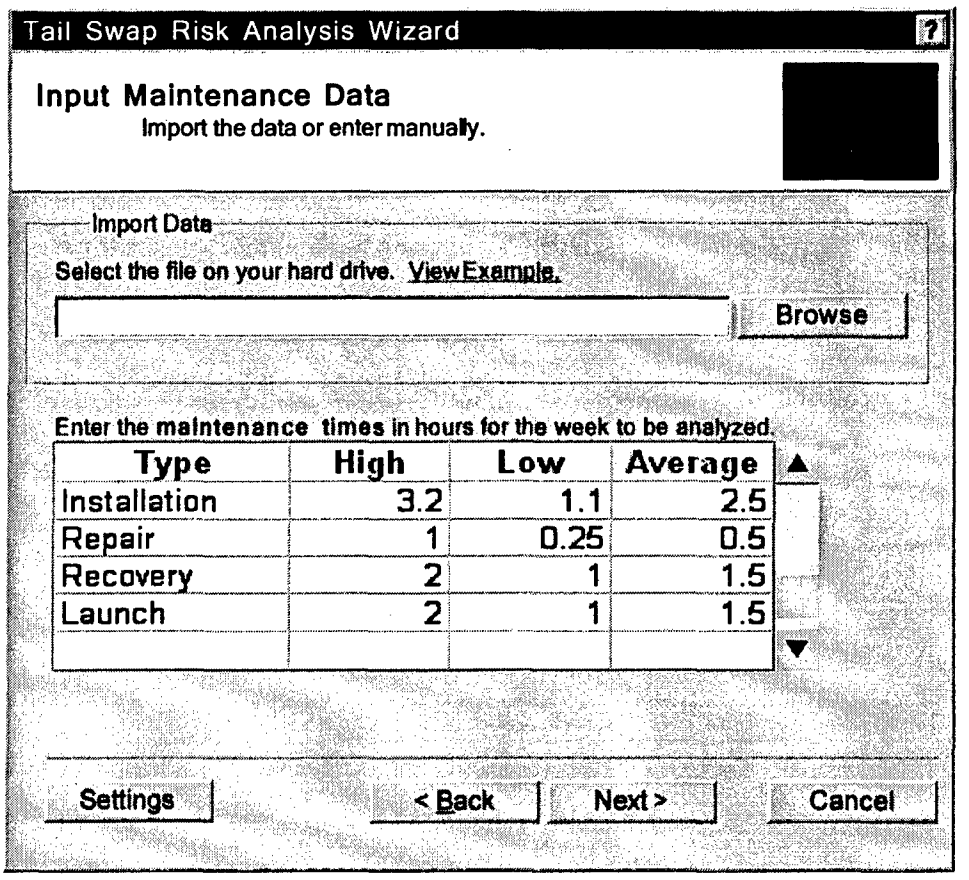

Figure 15: Input Maintenance Data

This screen allows the user to import the maintenance data to be used by the simulation model. The system uses the triangular distribution to model each of the events. Therefore the screen solicits the maximum, minimum, and average time period for each event. This information can either be imported or manually entered. If the data is imported the user will have the option to tweak the data once it is loaded into the wizard and displayed in the maintenance text area. The TYPE column refers to the event in the sortie generation process. The HIGH column refers to maximum time value for the event. The LOW column refers to minimum time value for the event. The AVERAGE column refers to mean time value for the event. Clicking the "SETTINGS" button will take the user to the settings window defined on the next page.

Clicking "NEXT" will take the user to the simulation settings window. Clicking "BACK" will take the user back to the aircraft availability screen. Clicking "CANCEL" will close the application.

6.2.5 Step Five

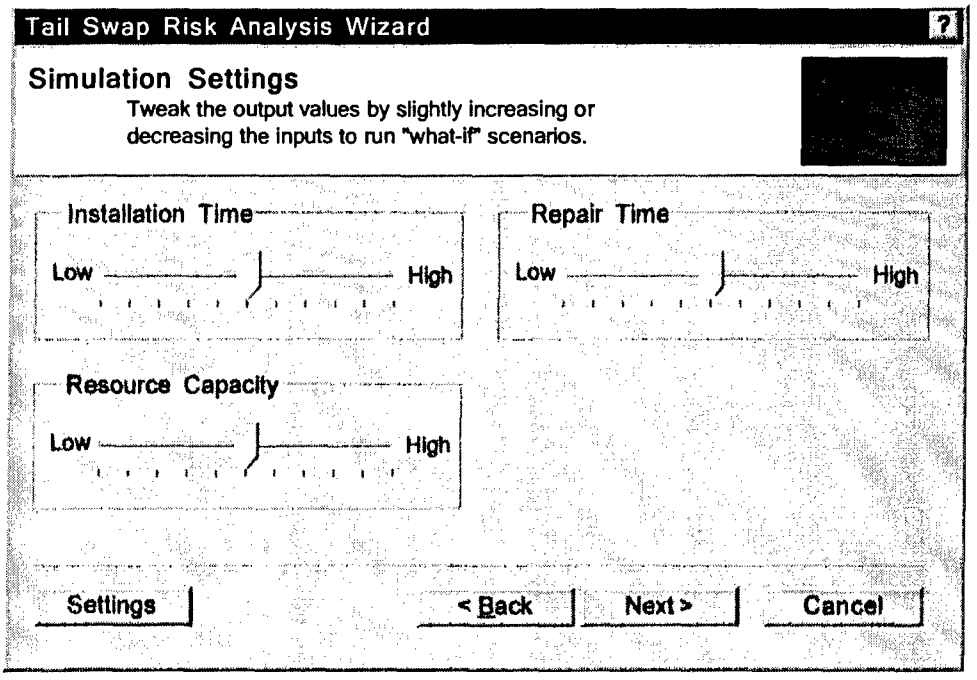

Figure 16: Simulation Settings

This screen allows the user to slightly modify the distributions from the maintenance data screen. During the first cycle of the application, the user is encouraged not to change the settings on this screen. Clicking the "SETTINGS" button will take the user to the settings window defined on the next page. Clicking "NEXT" will take the user to the simulation output window. Clicking "BACK" will take the user back to the maintenance data screen. Clicking "CANCEL" will close the application.

6.2.6 *Step Six*

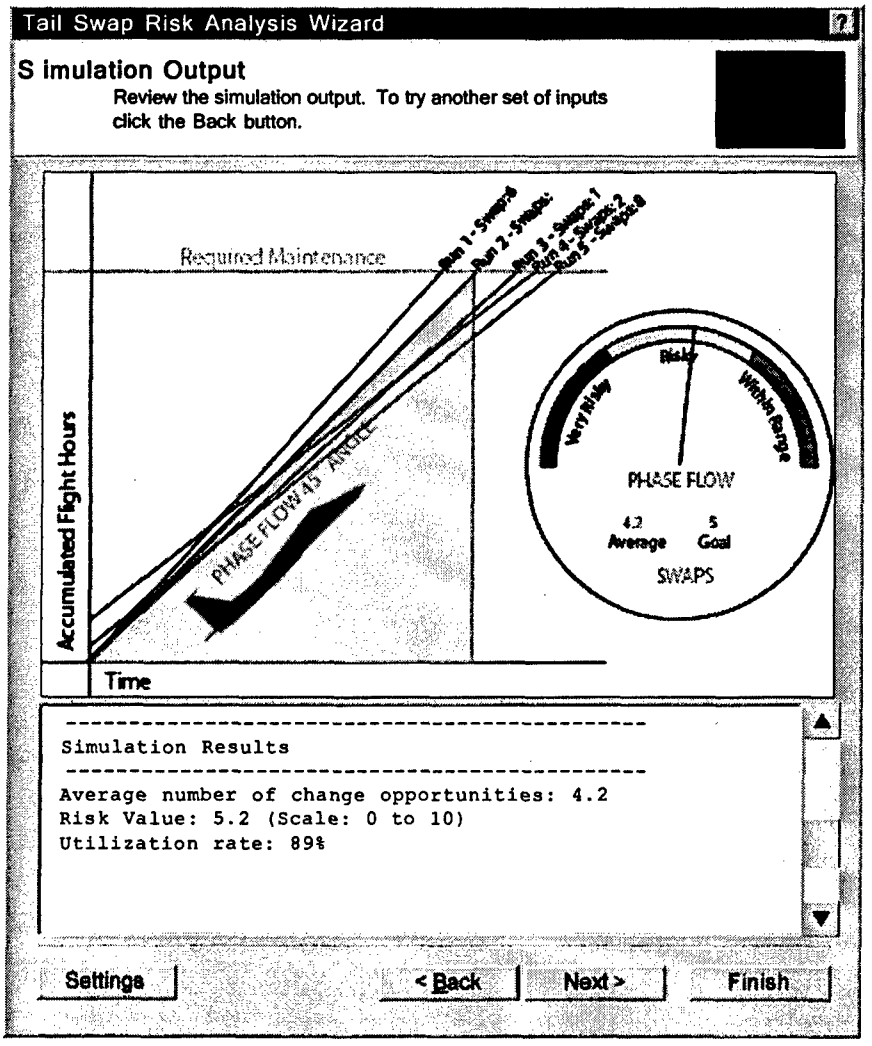

Figure 17: Output Data

This screen provides the user with the simulation output. To help gauge the risk to the aircraft availability and the utilization rate the risk gauge is shown. The gauge shows the average number of change opportunities the simulation model has found along with the goal value. The raw simulation data is also displayed in the textbox below. The phase flow angle is shown across the simulation runs, based on the variance across these runs the risk value is calculated. Clicking the "SETTINGS" button will take the user to the settings window defined on the next page. Clicking "NEXT" will take the user to the simulation settings window. Clicking "BACK"

will return the user to the simulation settings windows. Clicking "CANCEL" will close the application.

6.3 Second Cycle

The following sections will describe the second cycle in the DSS cycle. Each of the steps is illustrated with a screenshot followed by a description of the screenshot.

6.3.1 Step One

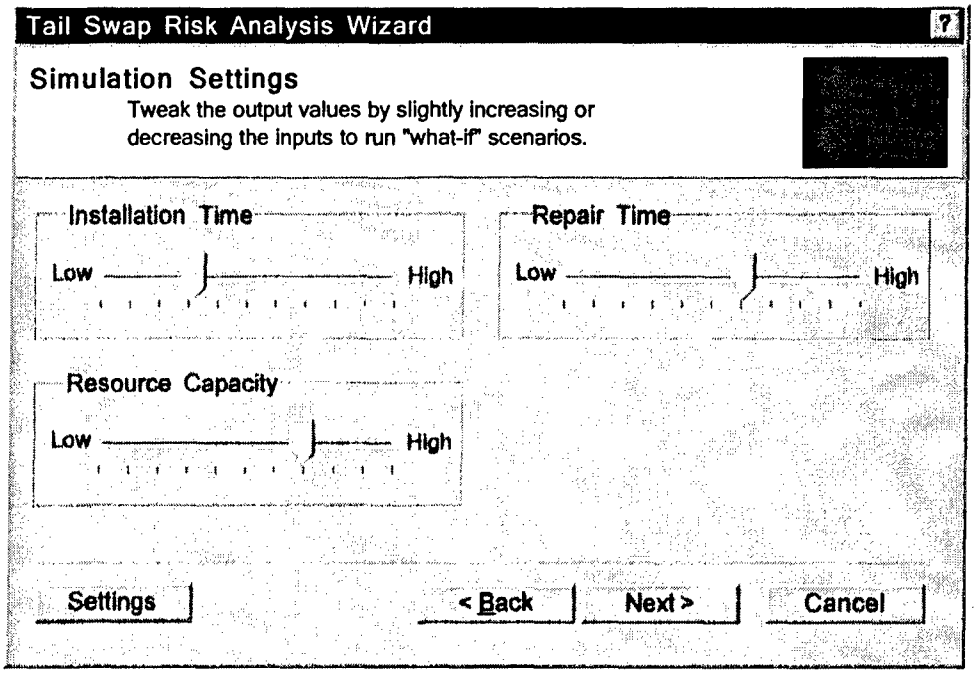

Figure 18: Modify Simulation Settings

This screen allows the user to slightly modify the distributions from the maintenance data screen. During the second cycle of the application, the user modifies the simulation settings to see if minor variations will help in the number of change opportunities or improve the phase flow angle. Clicking the "SETTINGS" button will take the user to the settings window defined on the next page. Clicking "NEXT" will take the user to the simulation output window. Clicking "BACK" will take the user back to the maintenance data screen. Clicking "CANCEL" will close the application.

6.3.2 *Step Two*

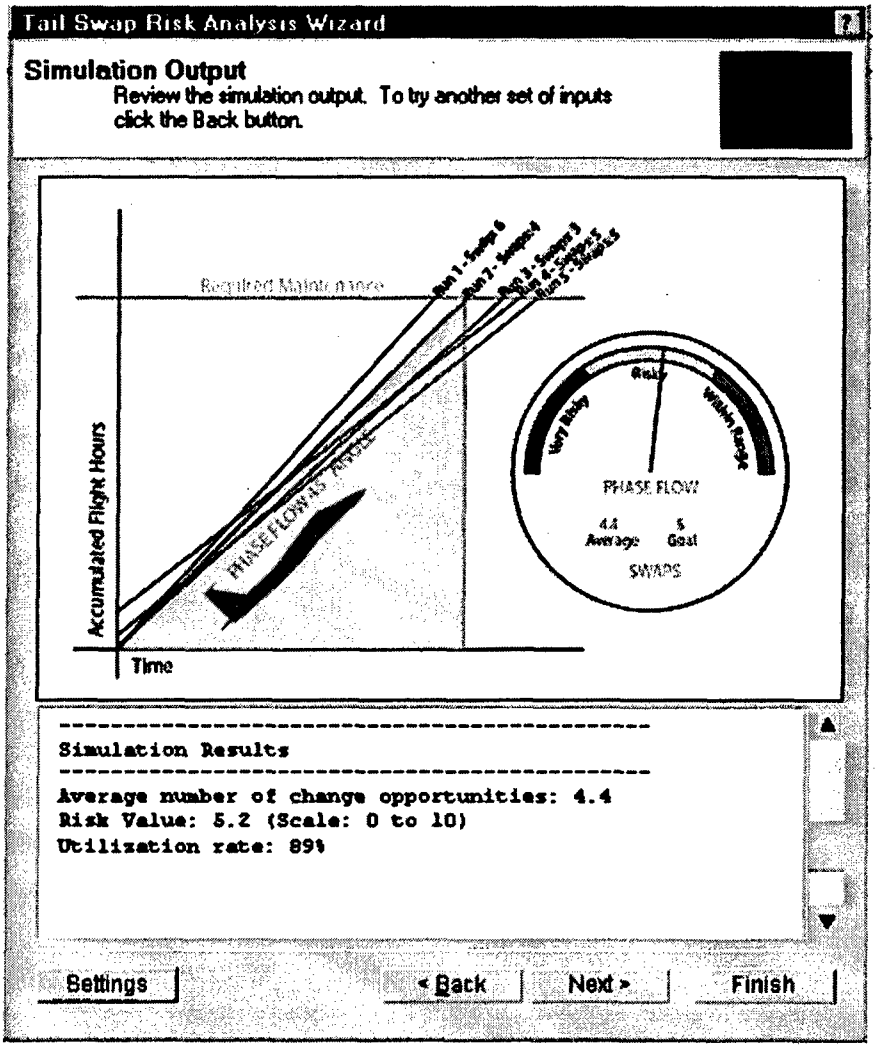

Figure 19: New Simulation Output

This screen provides the user with the simulation output. If the metrics are not significantly improved the user can select the "BACK" button to return to the schedule window to try a different schedule. If the user is comfortable with the results the schedule can be noted and that draft of the sortie schedule is selected. Clicking the "SETTINGS" button will take the user to the settings window defined on the next page. Clicking "NEXT" will take the user to the simulation settings window. Clicking "CANCEL" will close the application.

6.4 Formative Evaluation

Because there was so little access to potential users, the system was evaluated for usability using an inspection method known as heuristic evaluation. In order to perform the evaluation, a set of guidelines or heuristics must be established.

6.4.1 Design Heuristics

There are several recognized heuristics in the literature (Nielsen and Molich, 1990; Shneiderman, 1998). The most common are listed below:

- **Visibility of system status**

  The system should always keep users informed about what is going on, through appropriate feedback within reasonable time.

- **Match between system and the real world**

  The system should speak the users' language, with words, phrases and concepts familiar to the user, rather than system-oriented terms. Follow real-world conventions, making information appear in a natural and logical order.

- **User control and freedom ***

  Users often choose system functions by mistake and will need a clearly marked "emergency exit" to leave the unwanted state without having to go through an extended dialogue. An “undo” and “redo” functionality will be necessary for this reason.

- **Consistency and standards ***

  Users should not have to wonder whether different words, situations, or actions mean the same thing. Follow platform conventions.

- **Error prevention ***

  Even better than good error messages is a careful design which prevents a problem from occurring in the first place.

- **Recognition rather than recall ***

  Make objects, actions, and options visible. The user should not have to remember information from one part of the dialogue to another. Instructions for use of the system should be visible or easily retrievable whenever appropriate.

- **Flexibility and efficiency of use**

  Accelerators -- unseen by the novice user -- may often speed up the interaction for the expert user such that the system can cater to both inexperienced and experienced users. Allow users to tailor frequent actions.

- **Aesthetic and minimalist design**

  Dialogues should not contain information which is irrelevant or rarely needed. Every extra unit of information in a dialogue competes with the relevant units of information and diminishes their relative visibility.

- **Help users recognize, diagnose, and recover from errors ***

  Error messages should be expressed in plain language (no codes), precisely indicate the problem, and constructively suggest a solution.

- **Help and documentation**

  Even though it is better if the system can be used without documentation, it may be necessary to provide help and documentation. Any such information should be easy to search, focused on the user's task, list concrete steps to be carried out, and not be too large.

***Denotes heuristics that appear in both Shneiderman and Nielsen and Molich; otherwise heuristics are those suggested by Nielsen and Molich alone.**

Due to the nature of the application, we felt it necessary to include a few additional heuristics of our own devising. They are as follows:

- **Transparency**

  In expert level systems like a DSS, users need to know how figures were calculated. If calculation is made allow the user to drill down to see the root equation.

- **Contextual recognition of agent output**

  Simulation output numbers can overwhelm the user if they are not put into context of the problem. Present figures so that they can be easily mapped back into the decision context.

- **Data import rather than data input**

  To get an accurate simulation run, real world data is needed to create distributions and calculate means. Whenever possible, allow the user to input such values en lieu of making them hand code them back into the simulation model.

6.4.2 Heuristic Evaluation

Heuristic evaluation (Nielsen and Molich, 1990; Nielsen 1994) is a usability engineering method for finding the usability problems in a user interface design so that they can be attended to as part of an iterative design process. Typically, a small set of evaluators examines the interface and judges its compliance with recognized usability principles (the "heuristics"). The inspection of the interface is performed by the evaluator alone. During the evaluation session, the evaluator goes through the interface several times and inspects the various dialogue elements and compares them with a list of recognized usability principles (the heuristics). In addition to the

checklist of general heuristics to be considered for all dialogue elements, the evaluator obviously is also allowed to consider any additional usability principles or results that come to mind that may be relevant for any specific dialogue element. Furthermore, it is possible to develop category-specific heuristics that apply to a specific class of products as a supplement to the general heuristics. A supplementary list of category-specific heuristics was also provided to the evaluators. After all evaluations had been completed, the evaluators allowed to communicate with each other and have their findings were aggregated. This procedure is important in order to ensure independent and unbiased evaluations from each evaluator.

6.5 Test Scenario Inputs

This section will describe the data which was used in our test scenario. Table 2 describes the availability of aircraft. This table outlines the data described in section 5.3 used to initialize the state of the aircraft preceding the execution of the schedule. There are four main variables that define an aircrafts state tail number, availability, delay until ready, phase hours, and configuration.

Table 2: Initial Aircraft State

Tail Number	Availability	Delay(hours)	Hours Until Phase	Config.
010101	Available	0	56	Clean
010102	Available	0	57	Clean
010103	Available	0	7	Clean
010104	SM	Triangular(12,15,20)	17	Clean
010105	Available	0	246	Beta
010106	Available	0	191	Clean
010107	XCO	Triangular(24,25,27)	94	Gamma
010108	XCO	Triangular(24,25,27)	95	Gamma
010109	Available	0	96	Alpha
010110	DEMO	Triangular(169,175,180)	102	Alpha
010111	Available	0	51	Beta
010112	CANN	Triangular(200,224,280)	30	Alpha
010113	SM	Triangular(80,84,91)	134	Clean
010114	DEMO	Triangular(12,15,20)	115	Clean
010115	NMC	Triangular(50,58,60)	144	Alpha
010116	Available	0	167	Alpha
010117	Available	0	70	Clean
010118	PHASE	Triangular(60,63,67)	78	Gamma
010119	Available	0	21	Beta
010120	Available	0	266	Alpha
010121	Available	0	238	Alpha
010122	Available	0	91	Alpha
010123	Available	0	30	Beta
010124	Available	0	80	Beta

Table 3 describes the general plan for the schedule. As indicated in Table 3 the number of sorties for each run is outlined for each day on the schedule. In column 2 for Monday, 12/10 means that the schedule will require that we fly 12 aircraft in the first run and turn 10 aircraft for the second run.

Table 3: General Schedule

Day	Turns
Sunday	OFF
Monday	12/10
Tuesday	12/10
Wednesday	12/10
Thursday	12/10
Friday	10/8
Saturday	10/8

The following three tables describe the actual schedule the aircraft are to execute. Table 4 will include the schedule for Monday and Tuesday. Table 5 will include the schedule for Wednesday and Thursday. Finally, Table 6 will include the schedule for Friday and Saturday. Sunday will not be on the schedule due to the fact that in Table 3 it was defined as an off day. In the first column of these tables are the tail numbers of the aircraft followed by the configuration. The takeoff and landing times for flight/run one are then defined followed by the takeoff and landing times for flight/run 2. After the takeoff and landing times for flight/run 2, the following days schedule begins in the next column.

Table 4: Sortie Schedule 1

Tail #	Mon.	F1		F2		Tues.	F1		F2	
	Config.	TO	Land	TO	Land	Config.	TO	Land	TO	Land
10101	Clean	0800	0905	1600	1730	Clean	0800	0905	1600	1730
10102	Clean	0800	0905	1600	1730	Clean	0800	0905	1600	1730
10103	Clean	0800	0905	1600	1730	Clean	0800	0905	1600	1730
10104	Clean	SM				Clean	SPR			
10105	Beta	0750	0915	SPR		Beta	0750	0915	SPR	
10106	Clean	SPR				Clean	0800	0905	1600	1730
10107	Gamma	XCO				Gamma	XCO			
10108	Gamma	XCO				Gamma	XCO			
10109	Alpha	0805	0940	SPR		Alpha	0805	0940	1605	1720
10110	Alpha	DEMO				Alpha	DEMO			
10111	Beta	0750	0915	1550	1715	Beta	0750	0915	1550	1715
10112	Alpha	CANN				Alpha	CANN			
10113	Clean	SM				Clean	SM			
10114	Clean	DEMO				Beta	SPR			
10115	Alpha	NMC				Alpha	NMC			
10116	Alpha	SPR				Alpha	SPR			
10117	Clean	SPR				Clean	SPR			
10118	Gamma	PHASE				Gamma	PHASE			
10119	Beta	0750	0915	1550	1715	Beta	0750	0915	1550	1715
10120	Alpha	0805	0940	1605	1720	Alpha	0805	0940	SPR	
10121	Alpha	0805	0940	1605	1720	Alpha	0805	0940	1605	1720
10122	Alpha	0805	0940	1605	1720	Alpha	0805	0940	1605	1720
10123	Beta	0750	0915	1550	1715	Beta	SM			
10124	Beta	0750	0915	1550	1715	Beta	0750	0915	1550	1715

Table 5: Sortie Schedule 2

Tail #	Wed. Config.	F1 TO		F2 TO		Thur. Config.	F1 TO		F2 TO	
			Land		Land			Land		Land
10101	Clean	SM				Clean	SM			
10102	Clean	SPR				Clean	SPR			
10103	Clean	0800	0905	1600	1730	Clean	PHASE			
10104	Clean	SPR				Clean	SPR			
10105	Beta	0750	0915	1550	1715	Beta	0750	0915	1550	1715
10106	Clean	0800	0905	1600	1730	Clean	0800	0905	1600	1730
10107	Beta	SPR				Beta	SPR			
10108	Alpha	0805	0940	1605	1720	Alpha	0805	0940	1605	1720
10109	Alpha	0805	0940	1605	1720	Alpha	0805	0940	1605	1720
10110	Alpha	DEMO				Alpha	SM			
10111	Beta	0750	0915	1550	1715	Beta	0750	0915	1550	1715
10112	Alpha	CANN				Alpha	CANN			
10113	Clean	SM				Clean	SM			
10114	Beta	SPR				Beta	SPR			
10115	Alpha	NMC				Alpha	0805	0940	1605	1720
10116	Alpha	0805	0940	1605	1720	Alpha	0805	0940	SPR	
10117	Clean	0800	0905	1600	1730	Clean	0800	0905	1600	1730
10118	Gamma	PHASE				Clean	0800	0905	1600	1730
10119	Beta	0750	0915	SPR		Beta	0750	0915	SPR	
10120	Alpha	0805	0940	1605	1720	Alpha	0805	0940	1605	1720
10121	Alpha	SPR				Alpha	SPR			
10122	Alpha	0805	0940	SPR		Alpha	SPR			
10123	Beta	SM				Beta	0750	0915	1550	1715
10124	Beta	0750	0915	1550	1715	Beta	SM			

Table 6: Sortie Schedule 3

Tail #	Fri. Config.	F1 TO	Land	F2 TO	Land	Sat. Config.	F1 TO	Land	F2 TO	Land
10101	Clean	SM				Clean	SM			
10102	Clean	0800	0905	1600	1730	Clean	0800	0905	1600	1730
10103	Clean	PHASE				Clean	PHASE			
10104	Clean	0800	0905	1600	1730	Clean	SPR			
10105	Beta	XCO				Beta	XCO			
10106	Clean	SPR				Clean	SPR			
10107	Beta	SPR				Beta	SPR			
10108	Alpha	0805	0940	1605	1720	Alpha	0805	0940	1605	1720
10109	Alpha	0805	0940	1605	1720	Alpha	0805	0940	1605	1720
10110	Alpha	SM				Alpha	SM			
10111	Beta	XCO				Beta	XCO			
10112	Alpha	CANN				Alpha	CANN			
10113	Clean	SPR				Clean	0800	0905	1600	1730
10114	Beta	0750	0915	SPR		Beta	0750	0915	SPR	
10115	Alpha	0805	0940	1605	1720	Alpha	0805	0940	SPR	
10116	Alpha	0805	0940	SPR		Alpha	0805	0940	1605	1720
10117	Clean	0800	0905	1600	1730	Clean	SPR			
10118	Clean	SPR				Clean	0800	0905	1600	1730
10119	Beta	SPR				Beta	SPR			
10120	Alpha	0805	0940	1605	1720	Alpha	SPR			
10121	Alpha	SPR				Alpha	SPR			
10122	Alpha	SPR				Alpha	0805	0940	1605	1720
10123	Beta	0750	0915	1550	1715	Beta	0750	0915	1550	1715
10124	Beta	SM				Beta	SM			

6.6 Simulation

The schedule defined above along with initial aircraft states was used as input to the simulation model. The simulation was set to run for five replications using a different random number stream for each replication. Each replication yielded a set of output statistics. Following the initial replications we used the simulation to perform what-if analysis. The following sections will describe the output received from the simulation both in the initial replications as well as in the "what if" analysis.

6.6.1 Output

There were three interesting output statistics which we tracked in the simulation change opportunities, phase flow line, and number of aircraft down in need of repair. Change opportunities are defined as number of sorties not executed by the scheduled aircraft. This gives an indication of the number of human interactions with the schedule which would be needed to execute the schedule. Phase flow line describes a plot of the hours remaining until phase across all aircraft sorted in ascending order. When a LRU fails on an aircraft, that aircraft is considered NMC and is down in need of repair. We count the number of aircraft down needing repair throughout the simulation. Table 7 outlines the results from the 5 replications of the schedule. The results provided in Table 7 are averages across the five replications. In Table 7, the number of sorties for each day is displayed along with the number of sorties completed by the scheduled aircraft. The difference between these two values is the number of change opportunities. TCOWS refers to the Total Change Opportunities for the Weekly Schedule.

Table 7: Output Data

Day	Sorties Scheduled	Completed Sorties	Changes Needed
Monday	22	21.4	0.6
Tuesday	22	20	2
Wednesday	22	18.6	3.4
Thursday	22	19.4	2.6
Friday	18	16.2	1.8
Saturday	18	16.4	1.6
Sunday	0	0	0
Avg. Total Change Opportunities for Weekly Schedule			12
Standard Deviation of Avg. TCOWS			3
Average Weekly Total # of Aircraft Needing Unscheduled Maintenance			4

Figure 20 details the phase flow before the schedule was executed and then the average phase flow across the five replications after the schedule was executed. Also indicated on this graph is

the target phase flow line. The target slope is 12.5 or a straight line from 0 to 300. The goal of phase flow is to be close to that line and to have a high R^2 value meaning that all values fall close to the line. The initial phase flow was defined with a slope of 9.84, and the average ending slope was 9.64. This indicates that our schedule did not change the phase flow much but it did move it slightly away from target. To fix the phase flow in the graph one would fly more hours off of the aircraft with fewer available hours, and hold back the aircraft in the dip in the middle of the graph. This would increase both the R^2 and the slope of the line.

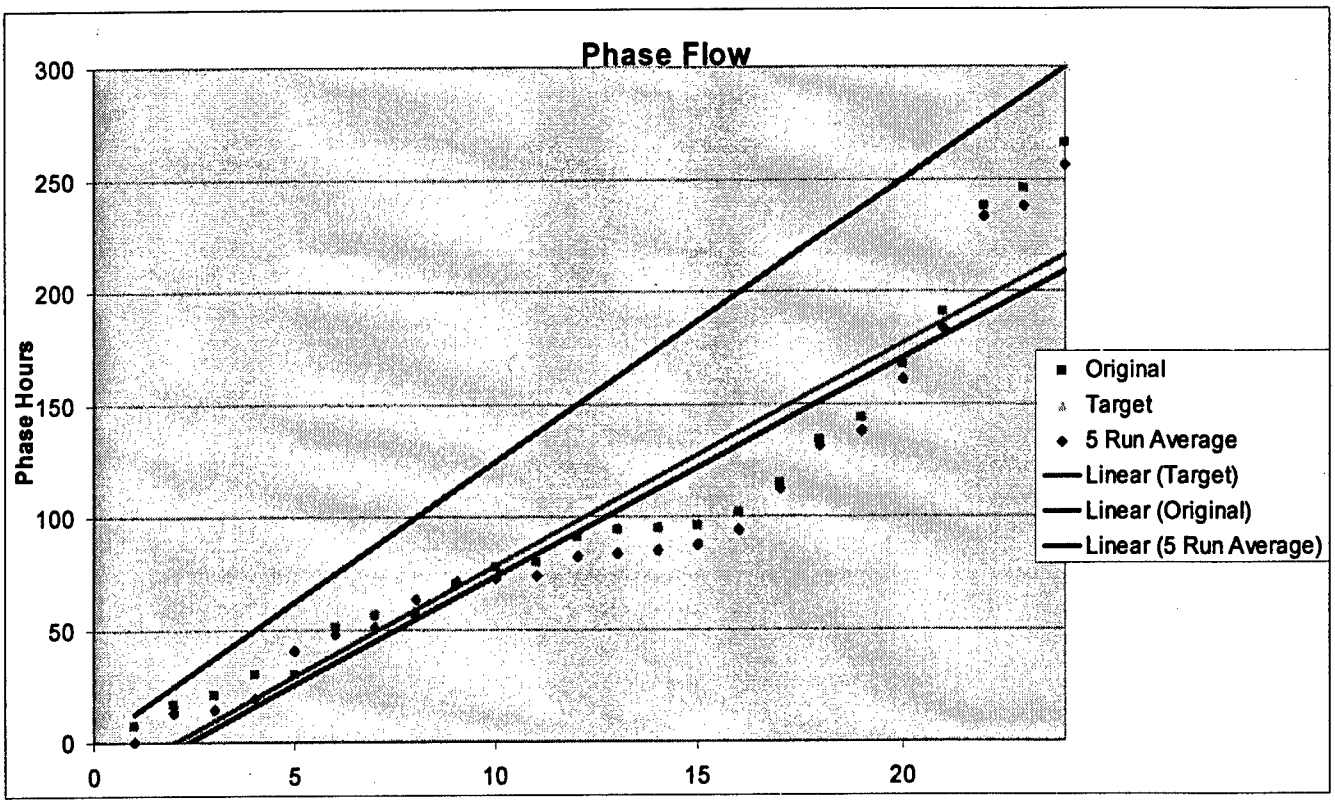

Figure 20: Phase Flow

6.6.2 What-If Scenarios

After completing our initial replications of the schedule we performed some what-if analysis. We developed two scenarios and ran the simulation with slight variations in input parameters to see what would happen. The first scenario we ran was one where supply will take 20% longer to

be shipped between the base and the depot. Table 8 outlines the summary output statistics for this scenario. As indicated in Table 8, there was an increase in the number of change opportunities as well as the variability in the number of change opportunities.

Table 8: Supply What-If

Day	Sorties Scheduled	Completed Sorties	Changes Needed
Monday	22	21.4	0.6
Tuesday	22	20	2
Wednesday	22	19	3
Thursday	22	18.2	3.8
Friday	18	15.2	2.8
Saturday	18	15.6	2.4
Sunday	0	0	0
		Change Opportunities	14.6
		Standard Deviation	3.5777
		Average Phase Flow Slope	9.6407
		Average Weekly Total # of Aircraft Needing Unscheduled Maintenance	3.8

The second scenario involved the maintenance and installation processes taking 25% longer to complete during the scheduled week. Table 9 outlines the summary output statistics for the second scenario. As indicated in Table 9 increasing the maintenance and installation times greatly increased the number of change opportunities as well as increasing the variability in the number of change opportunities experienced.

Table 9: Maintenance What-If

Day	Sorties Scheduled	Completed Sorties	Changes Needed
Monday	22	21.2	0.8
Tuesday	22	19.6	2.4
Wednesday	22	19.8	2.2
Thursday	22	17.6	4.4
Friday	18	14.2	3.8
Saturday	18	14.6	3.4
Sunday	0	0	0
Change Opportunities			17
Standard Deviation			3.8730
Average Phase Flow Slope			9.6272
Average Weekly Total # of Aircraft Needing Unscheduled Maintenance			4.8

7 Summary and Conclusions

In the course of this report we have introduced the concept of using simulation to provide support at the unit level. We then developed a simulation model based on an USAF sortie generation problem. This simulation was used to execute a predefined weekly schedule and analyze its effectiveness also allowing the user to perform what-if analysis with schedule inputs. A user interface was also developed for this simulation to allow users to quickly and easily provide input data as well as view and interpret results. These two pieces when placed together constitute the goal of this research which was stated as the development of a proof of concept tool demonstrating the usefulness of simulation in aiding unit level decision makers.

One of the major limitations of the system was that the data used were from theoretical distributions were not from a real world sources. The Air Force has vast amounts of information available about the wing and individual weapon systems. Finding a way to directly import this information would be extremely valuable to a system such as the one described in this report.

The DSS would have been much more powerful if we had had access to the real world information and to the data formats it is stored in.

Future research should explore the possibility of adding more agents to the decision support system. For example, in our research we used a simulation model to perform what-if analysis to help validate schedules. An additional agent could be created that searches a knowledge base for similar scenarios to help validate the schedule against past schedules under similar circumstances. Another agent might optimize the schedule against a certain metric, utilization for instance, and then the schedule could be run in what-if scenario for further analysis. Further research could also be pursued in the following areas:

- Enhance Simulation Model
  - Incorporate more change logic into model
  - Extend model to other aspects of flight line
  - Develop and capture additional performance metrics
- Enhance User Interface
  - Explore portable issues so it can be used on the flight line (i.e. PDA, web-interface)
  - Allow the user to modify the simulation so it more closely matches their specific situation
  - Additional visual or multi-criteria displays of schedule risk
  - Additional user testing
- Examine ways to generate heuristic or optimal schedules to the user
  - Model schedule as optimization problem
- Examine deployment issues

- The Air Force has a large amount of data available in multiple formats.
- Connecting decision support tools such as the one developed in this research to those data sources could be very valuable
- Access to AF data formats (i.e. CAMS, TASAMS)

We have analyzed the challenges associated with applying simulation based decision support systems at the unit level. The development of the prototype and its design/testing indicate that simulation technology augmented by enhanced user interaction technology clearly can improve the decision capabilities of unit level logistic planners. It remains to further enhance these tools with the additional agent concept, and to develop deployable field tests to fully evaluate the use of this important technology

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Appendix 1

Baseline Model Inputs and Distributions

Parts	
Number of LRUs	6
Number SRUs-LRU1	4
Number SRUs-LRU2	4
Number SRUs-LRU3	4
Number SRUs-LRU4	4
Number SRUs-LRU5	4
Number SRUs-LRU6	4
Time to Failure Distribution for SURs in Hours - Each of these distributions corresponds to a set of eight SRUs within the system.	Exponential (300) Exponential (400) Exponential (500)
Inventory at Base Level for all SRUs	3
Inventory at Depot Level for all SRUs	20
Repair Time Distribution for all SRUs in Hours	Exponential (8)
Number of Repair Resources at the Base Level	Unlimited Capacity
Number of Repair Resources at the Depot Level	Unlimited Capacity
Queuing rules for repair	Backorders parts are given top priority in the repair process
Probability that a Part can be Repaired at the Base Level	.01
Shipping	

Number	Distribution (Hours)	Description
1	TRIA(12,81.6,184.8)	This distribution is used to generate shipping times between bases in the same region.
2	TRIA(31.2,170.4,348)	This distribution is used to generate shipping times between the depot and the bases in region 1.
3	TRIA(76.8, 266.4, 453.6)	This distribution is used to generate shipping times between the depot and the bases in region 2. This distribution is also used to generate the shipping time between bases which are not in the same region.

Shipping Time Distribution Matrix						
	Base1	Base2	Base3	Base4	Base5	Base6
Base1	0	1	1	3	3	3
Base2	1	0	1	3	3	3
Base3	1	1	0	3	3	3
Base4	3	3	3	0	1	1
Base5	3	3	3	1	0	1
Base6	3	3	3	1	1	0
Depot	2	2	2	3	3	3

MICAP Shipping Time in Hours	TRIA(22, 24, 26)
Maximum LTL Load in Number of SRUs	20
Minimum LTL Load in Percent of Max Load	0.2
Structure (refer to Figure 1)	
Number of Planes Per Unit	24
Number of Units Per Squadron	3
Number of Squadrons Per Base	1
Number of Bases	6
Number of Regions	2
Number of Bases Per Region	3
Number of Depots	1
Phase Inspection	
Accrued Flight Hours Before Base phase inspection	290-305 Flight Hours
Base Phase Inspection Time Distribution in Days	Triangular (5,7,10)
Repair Resources Required for Phase Inspection	50
Queuing Rules for Phase Inspection	First In First Out

Pre Flight Operations	
Refuel	Triangular (8,10,12) minutes
Weapon Load	Triangular(25,30,35) minutes
Pre-Flight	Triangular(50,60,70) minutes
Engine Start, Final Systems Check, and Taxiing	Triangular(7,10,12) minutes
Takeoff	Triangular(2,3,4) minutes
Post Flight Operations	
Landing	Triangular(14,15,16) minutes
Parking and Recovery	Triangular(5,7,9)-2 minutes
Final Parking	2 Minutes with LRU clock stopped
Service and Debrief	Triangular(45,60,75) minutes
Unscheduled Maintenance Operations	
Troubleshooting	Triangular(20,24,30) minutes
Remove Part	Triangular(45,60,70) minutes
Wait for Part to issue from supply	Triangular(.5,2,2.5) hours
Delay for paperwork	Triangular(5,10,15) minutes
Installation	Triangular(60,84,120) minutes
Operational Check	Triangular(15,20,25) minutes
Signoff Discrepancy	Triangular(5,10,15) minutes
Document Corrective Action	Triangular(5,10,15) minutes