Building the Mobility Aircraft Availability Forecasting (MAAF) Simulation Model and Decision Support System

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The Mobility Aircraft Availability Forecasting (MAAF) model prototype development and study effort was initiated to help the United States Air Force Air Mobility Command (AMC) answer the question, “How can we accurately predict mission capable (MC) rates?” While perfect prediction of aircraft MC rates is not possible, we investigate a simulation-based risk analysis approach. Current prediction methods utilize “after the fact” analyses and user opinion, making it difficult to perform quick, accurate, and effective analyses of potential limiting factors and policy changes, particularly in time-sensitive situations. This paper describes the MAAF proof-of-concept model and decision support system built to provide AMC managers the dynamic, predictive tools needed to better forecast aircraft availability. The simulation component featured new capabilities for mobility modeling to include dynamic definition of the configuration of a mobility system, dynamic definition of the capabilities of the individual airbases within a mobility system, improved representation of the aircraft objects within the model, and a new approach to modeling aircraft maintenance including the realistic consideration of partially mission capable aircraft. The development efforts and sample experimental results are recounted in this paper.

Keywords: Simulation, logistics, mobility, decision support

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1. Introduction

The Mobility Aircraft Availability Forecasting (MAAF) model is an object-oriented decision support system interface, database, and analytical simulation built as a proof-of-concept requirements analysis and feasibility demonstrator. The primary objective of a MAAF is to provide mobility and logistics analysts in the United States Air Force Air Mobility Command (AMC) a quantitative-based means for predicting and assessing the availability of aircraft under normal operating conditions and under a variety of operational scenarios. Our prototype captures the essential characteristics of a MAAF and demonstrates its viability via a demonstration scenario.

Simulation, modeling, and analysis provide insight into the nature of decision alternatives considered in a real-world system. Decision making involves the identification, evaluation, and comparison of alternative actions. These actions are evaluated based on the many varying conditions inherent in the particular decision-making situation, a situation that can be quite complex. Models, particularly simulation models, are very useful for examining and gaining insight into such complex situations. Although models are by necessity approximations of any real system, Schmidt [1], among many, believes that even such approximations can yield important information about the actual system under study. The MAAF research design goal was to reasonably represent the key drivers of aircraft availability in a simulation model of the real-world mobility system.

This paper describes the MAAF decision support model developed and applied to a notional yet representative operational planning scenario. MAAF was built to support a mobility headquarters analytical function. In particular, the MAAF was built to help mobility logistics analysts determine how many aircraft can be declared available for mission tasking under normal flying operations as well as under any planned operational scenarios. The MAAF was also designed to explore "what if" analyses to provide analysts some predictive insight into force management options within the AMC. Specifically, AMC analysts needed insight into how to manage aircraft and maintenance personnel (and resources) to maintain desired levels of mission capability under a variety of mission tasking scenarios.

2. Background

The Air Mobility Command (AMC) provides airlift, air refueling, special air mission, and aeromedical evacuation for U.S. forces. As the Air Force component of the United States Transportation Command (USTRANSCOM), AMC is the single manager for air mobility. The command operates from 13 stateside bases, 6 units at non-AMC bases (both stateside and overseas), and 71 Air Reserve Component units gained by AMC in times of mobilization (42 Guard and 29 Reserve). The AMC Directorate of Logistics (AMC/A4) develops concepts and manages logistic support for all AMC missions in both peacetime and during contingencies. It is responsible for ensuring that the mobility fleet, consisting of a total of 544 various aircraft, is capable of accomplishing the mission of AMC [2].

Currently, the AMC Logistics Directorate does not possess sufficient capability to forecast, assess, or evaluate alternatives impacting aircraft availability—something that is key to the AMC decision-making process. This deficiency makes it very difficult for the maintenance division within the directorate to perform quick, accurate, and effective analyses of potential limiting factors and policy changes. Current methods utilize "after the fact" analyses, such as time series models or simple trend projections, or the experience of various managers to determine the best courses of action. These procedures can be very labor intensive with the forecasts ultimately based on the experience of the personnel involved.

To address this analytical deficiency, we examined the requirements for a MAAF. We demonstrated how an object-oriented–based modeling and simulation application for mobility planners and analysts could help provide insight on problems or limiting factors impacting aircraft availability in both a short- and long-term planning horizon. In addition to predicting aircraft availability based on projected mission requirements, our MAAF assists logistics planners and analysts in assessing potential resource shortfalls that may occur due to policy changes and helps quantify those impacts in terms of mission capability and aircraft availability before implementing those policies.

3. Related Research

Military analyses depend upon models. Models help analysts examine critical issues such as allocation of resources, training, the equipping of military forces to meet military demands, and the procurement and maintenance of weapons and weapons systems. The mobility analysis environment makes use of classic mathematical programming methods, modern heuristic optimization methods, and simulation-based tools. A current challenge is to provide mobility analysts insight into the airlift aircraft needed to meet routine and non-routine mission requirements, where these mission requirements usually imply worldwide commitments of aircrews and aircraft. Worldwide commitments mean analysts must explicitly consider long aircraft mission periods, potential system failures and repairs while aircraft are on those missions, and resource limitations at worldwide locations that may limit both repair and aircraft preparation efforts. Simulation is a well established risk-assessment tool useful for such complex scenarios. The information generated by the MAAF simulation and decision support environment developed in this research evaluated the effects of resource levels on the overall performance of an airbase within an air mobility system. Through the use of MAAF, an analyst can determine whether the aircraft and resources allocated to an airbase can support the missions assigned to that airbase and transient through the airbase.

3.1 Simulation and Mobility Logistics

Carter and Litko [3] describe the channel simulation model, CARGOSIM. CARGOSIM balances the goals of aircraft utilization and delivery timeliness, both of which are important challenges faced by the AMC. AMC must make best use of their limited supply of aircraft to fulfill their mission. CARGOSIM inputs include the routes taken by the planes; various schedules; the aircraft properties, such as capacity, speed, and ground time; and the cargo generation. Model output includes plane utilization and route utilization along with the cargo movement times and any backlogs predicted.

Balaban et al. [4] use a simulation model to estimate aircraft readiness based on the *mission capable rate* (MCR), specifically for the C-5 Galaxy aircraft, using the usual readiness categories: fully mission capable (FMC), partially mission capable (PMC), and non-mission capable (NMC). They examine three C-5 configuration alternatives to determine a best alternative for the Air Force to meet its cargo airlift operations and present details on the MCR for each configuration alternative. A low MCR means reduced availability of the aircraft and hence reduced airlift capability. An important result from the study showed the C-5 could achieve a 75% MCR through implementation of one of the examined configuration alternatives.

Simulation-based approaches have been used to examine the effect of reducing the amount of support equipment required by a deploying aerospace combat force [5, 6]. The Air Force needs reduced deployment inventories to speed up operational deployments without significantly reducing operational effectiveness. Reduced deployment requirements make more effective use of mobility aircraft assets. A simulation model was developed to examine the potential impact of reducing support equipment deployment requirements. Using expected aircraft flying rates and historical subsystem failure rates, equipment utilization estimates were used to assess support equipment criticality. Less critical items can be removed from immediate deployment providing the possibility of significant deployment inventory reductions [6].

Narayanan et al. [7] present the Java-based Architecture for Developing Interactive Simulations (JADIS). JADIS is a visual interactive simulation (VIS) architecture used for the modeling and analysis of the airbase logistics for an F-16 fighter airbase. The modeled airbase includes resources such as personnel, equipment, spare parts, and hangar. It models fighter sortie generation based on actual flying rates. The model is used to answer analytical questions pertaining to logistics capabilities and provides the initial MAAF basic discrete event simulation infrastructure. The MAAF also extends some of the JADIS airbase objects to accommodate mobility airbase operations; see Narayanan et al. [7] for details.

Burke et al. [8] discuss the transportation system capability (TRANSCAP) model. TRANSCAP focuses on the initial stages of an army deployment, the loading of material at the home station. The model does not consider mobility aspects required to move the loaded material to the deployment destinations. Leathrum Jr. et al. [9] describe a simulation architecture for examining intra-theater sealift operations and demonstrate the use of the architecture using a notional scenario.

3.2 Optimization and Mobility Logistics

Large-scale mathematical modeling has long been used for mobility applications. Mattock et al. [10] provide a nice introduction to the use of mathematical modeling for mobility analyses. Morton et al. [11] describe THRUPUT II, a time-dynamic linear programming model focused on strategic airlift assets. Model employment is discussed with a realistically-sized deployment scenario. (This model was later extended, and those extensions are described in [12].) Baker et al. [13] describe the NPS/RAND Mobility Optimizer (NRMO), a large-scale linear program accommodating many of the capabilities in predecessor models. Two case studies are described, one involving an airfield capacity study and the second a fleet modernization study. Recently, Nielson et al. [14] present a network-based linear programming model for determining schedules for AMC channel routes, the routes used to routinely deliver cargo and personnel around a mobility system. McKinzie and Barnes [15] provide a comprehensive review of both legacy and emerging strategic mobility models.

Pre-positioning strategies are used by the military to augment mobility and logistics capabilities. The Air

Force Logistics Management Agency [16] examines pre-positioning munitions using the Joint Integrated Contingency Model. This study examines a realistic scenario and produces a number of recommendations for the Air Force. Sentlinger [17] presents a mixed-integer program examining the optimal weapons pre-positioning mix for established U.S. Naval weapon stations with a focus on minimizing demand shortfalls during a myriad of conflicts. Anderson [18] describes an optimization model that utilizes available shipping assets to redistribute weapons based on a pre-determined positioning plan for the Pacific Fleet. However, Anderson's optimization model only examines the redistribution of weapons based on routine, scheduled deployments and is not tied to any wartime scenario. Finally, Johnstone et al. [19] develop and test a mixed-integer model to examine the pre-positioning fleet configuration and placement, along with deployment planning to meet precision munitions demand requirements in a multiple-scenario planning environment pulling munitions assets from multiple locations through the use of air, land, and sea mobility assets. The model in Johnstone et al. [19] is tested and demonstrated on a scenario drawn from actual practice.

3.3 Modern Heuristics and Mobility Logistics

Recent research has employed modern heuristic approaches as a means to obtain reasonable solutions to more complicated, more detailed types of mobility problems. Crino et al. [20] provide a conceptual framework, based on the tabu search heuristic, for modeling and solving the multi-modal theater distribution problem. This work integrates the scheduling and routing of theater assets at the individual asset level. Barnes et al. [21] employ a tabu search approach in developing a tool for aerial fleet refueling (tanker) scheduling. Their tool is benchmarked against existing tanker scheduling tools and found to provide answers more quickly while returning solutions that required fewer tankers, traveled fewer miles, and accomplished the mission in a shorter period of time.

4. MAAF Simulation Architecture

The MAAF simulation extends the earlier JADIS architecture (of [7]) to accommodate the modeling of a system of airbases such as those found in the mobility systems domain. A unique feature of both the MAAF and JADIS architectures is their use of decision-making

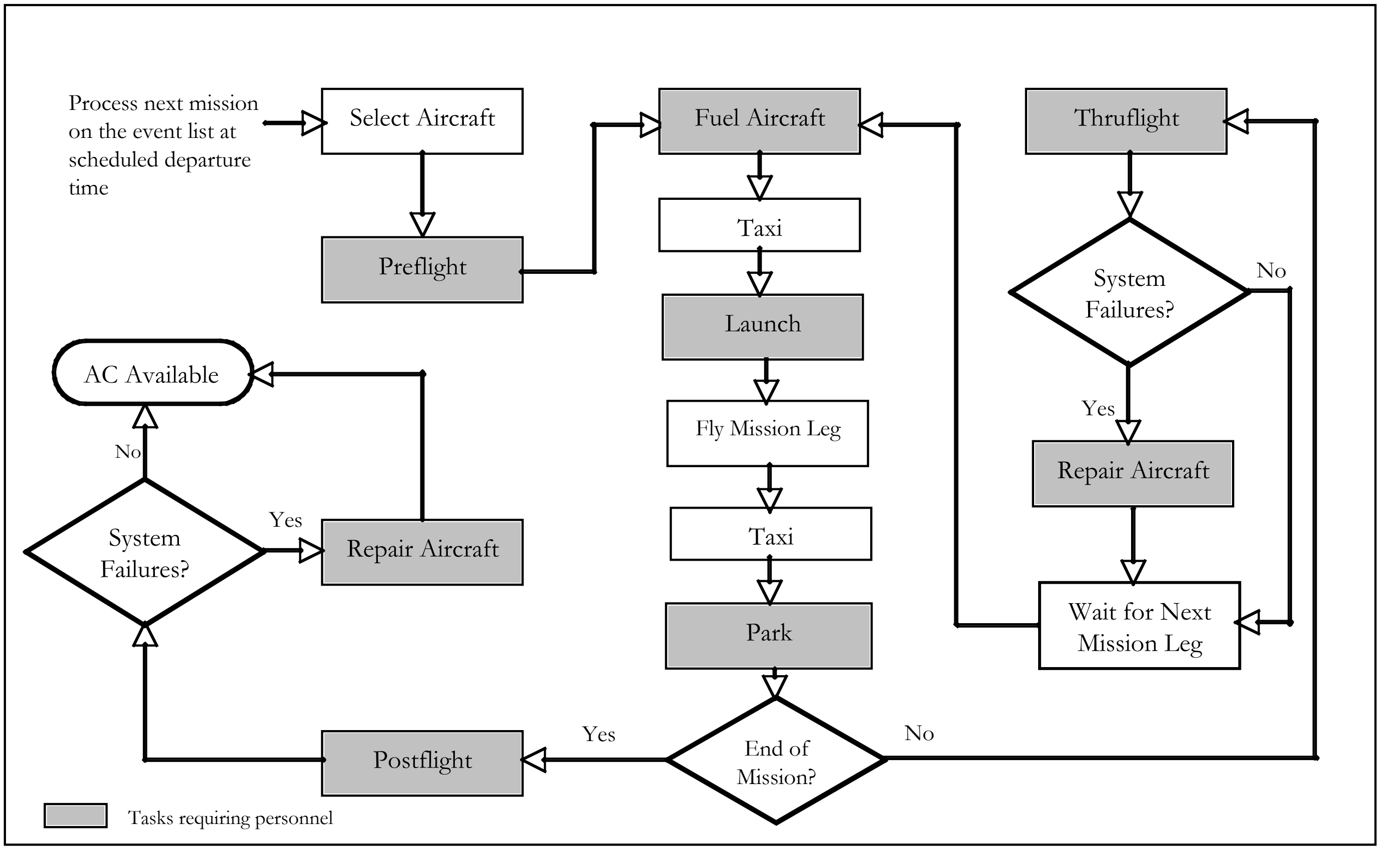


Figure 1. Block diagram illustrating activities modeled at a MAAF airbase

objects. These objects map to real-world functions accomplished within the airbase logistics domain and are used in the simulation model to control the flow of objects and resources.

Modeling mobility aircraft missions (as required in MAAF) is more complex than modeling fighter aircraft missions (as implemented in JADIS). Mobility missions can involve stops at multiple bases and span multiple days. Mobility aircraft may land at en route locations possessing a minimal support infrastructure and lacking in maintenance capabilities for anything beyond routine maintenance and refueling. Thus, the MAAF architecture is designed to capture the movement of mobility aircraft within a system of heterogeneous airbases. The activities that are modeled at each of these airbases are depicted in Figure 1. While somewhat similar to flowcharts found in related simulations of airbase logistics and flight operations, note the explicit consideration of aircraft (AC) in thruflight (stopping at the current base while on larger missions) and the consideration of aircraft from the current base (block labeled "Select Aircraft") for missions assigned to that airbase.

The primary challenges in building the MAAF simulation architecture are providing the capabilities to capture:

- The movement of aircraft among bases in a mobility system;
- The repair of aircraft at non-home station airbases;
- The assignment of aircraft to missions when aircraft are partially mission capable (PMC);
- The delay of non-critical repairs until the aircraft is back at the home station; and
- The preparation of en route aircraft for the subsequent missions.

A MAAF simulation scenario is dynamically defined. Input data files are created using a graphical user interface to define each base, its location, the assets present at the base, and the missions originating at each base. This definition produces a tailored simulation model of a mobility system. This approach provides analytical flexibility in terms of examining a variety of mobility systems and assessing the mission capabilities of planned operations; many tailored simulations or projects can exist within a single MAAF decision support environment.

MAAF includes an additional level of dynamic model definition providing the usual capability of dynamically defining the parameters used to execute each simulation run. This capability provides a means to conduct probing "what if" analyses within some defined simulation scenario. Input missions match actual mission data as much as possible—for instance, aircraft, base of mission origin, set of destination bases, take-off times for each leg of the mission, and arrival times at each of the destination bases are sample data items provided in an input mission.

4.1 MAAF Decision-Making Objects

Figure 2 provides a representation of the inheritance and functional relationships among key MAAF simulation objects; key objects are described in detail below. The Aircraft object represents the individual aircraft within a modeled mobility system. The MAAF Aircraft object requires thorough knowledge of its current mission. Unlike a fighter aircraft object, the MAAF aircraft requires knowledge of where it is in the sequence of legs, or stages, on its mission; its current status with respect to its functioning systems (i.e., fully, partially, or non-mission capable); and any minor repairs awaiting attention upon its return to its home station (the base to which the aircraft was originally assigned). This concept of holding minor repairs in abeyance is novel to the MAAF model and is discussed further below.

The Airbase object represents each airbase in a mobility system and all the elements that comprise that airbase. The MAAF Airbase object accepts transient aircraft objects as well as its own aircraft objects. Thus, MAAF Airbase objects not only generate their own missions with their assigned aircraft but also accommodate operations for those other aircraft currently at the base whose missions originated at some other airbase.

There are Mission Manager objects that support each Airbase object. The Mission Manager maintains a list of missions needing aircraft. The Mission Manager maintains knowledge of all missions emanating from the particular airbase (both indigenous aircraft and en route aircraft) and determines when preflight activities must begin for an aircraft to take off at its scheduled time for its assigned mission.

The Shift Manager object manages the initialization and termination of maintenance personnel shifts within an airbase. In airbase operations, any maintenance shift is composed of a mix of personnel having a mix of maintenance qualifications. For MAAF, maintenance personnel are modeled as separate objects. This provides a facility to assign personnel to shifts and, while on the shift, to assign those personnel to specific maintenance tasks for which they are qualified. This also provides a future capability to model detailed personnel issues such as training, sick days, etc., that arise in real-world situations but are rarely explicitly considered in model-based analyses.

The Shift Manager object makes use of a Job object. All activities within an airbase are jobs. This Job

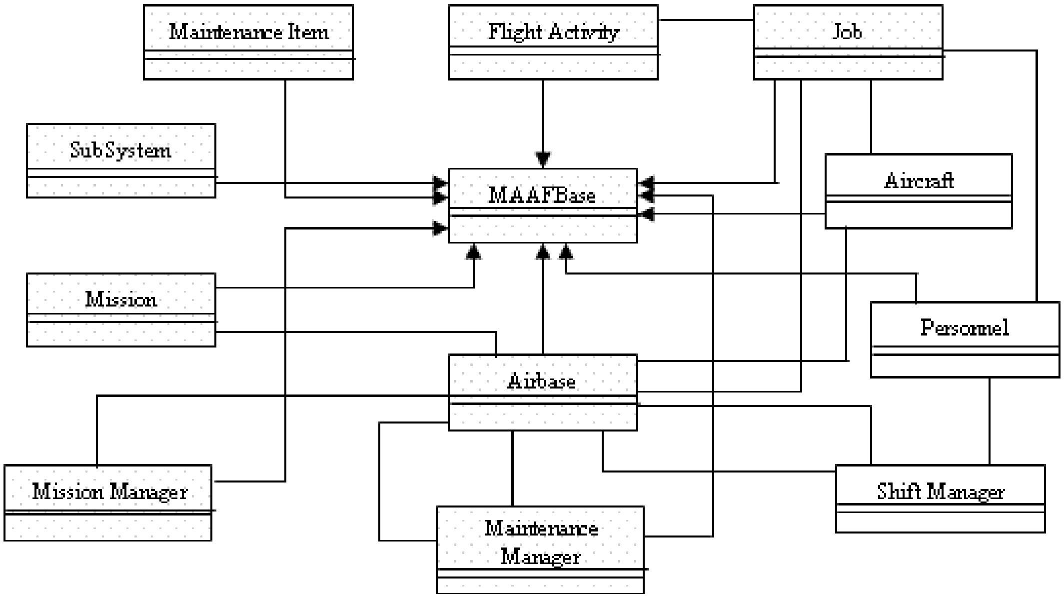


Figure 2. UML class diagram depicting salient objects in MAAF simulation

object facilitates aircraft maintenance processes, the management of personnel objects assigned to maintenance tasks, and the handling of personnel shortages and job interruptions due to shift change actions.

4.2 Maintenance Modeling in MAAF

The MAAF simulation model extends the modeling of maintenance for mobility systems in two crucial ways: lack of maintenance resources at an en route location and criticality of the required maintenance activity. A key aspect of any mobility system involving en route airbase locations is the limited availability of personnel; the lack of personnel can ground an aircraft requiring repairs the airbase cannot accommodate. In actual practice, an aircraft can fly missions while needing minor maintenance or, specifically, non–mission critical maintenance postponed until some later, more convenient time; these are aircraft considered PMC.

In most simulations of airbase activities, any maintenance activity must request specific numbers of different types of maintenance resources (i.e., personnel or equipment). When such resources are deemed unavailable by the model, the activity can get "stuck" in the associated resource queue. In actual operations, special teams are dispatched to accommodate such delayed repair activities. For MAAF, the maintenance activity model was extended to consider the availability of base resources versus the resources required by the maintenance action. An aircraft requiring maintenance is placed in the appropriate resource queue. If the base has sufficient capabilities, the maintenance jobs are initiated once the resources become available and are assigned to the aircraft. Once a resource is assigned MAAF tracks its utilization. If the base does not have sufficient capabilities, the aircraft remains in the queue until the special repair team arrives. (This special team arrival is modeled as a delay in MAAF.)

In actual air operations, the minimum essential subsystem list (MESL) determines the capability of an aircraft with respect to specific missions. In actual practice, a repair to a non-essential subsystem can be postponed during a multi-leg mission provided that subsystem is not critical to the accomplishment of the remaining legs of the mission. The aircraft is no longer FMC but is now considered PMC. These nagging repairs are usually accomplished upon return to home station. Most mobility simulations fail to fully capture these PMC considerations, thus potentially understating the mobility system mission capability. Our database includes MESL information for each of the aircraft subsystems considered.

The Maintenance Manager object directs the maintenance processes within the MAAF simulation. The Maintenance Item object for each particular aircraft subsystem carries the subsystem name, the MESL information, the subsystem mean time between failures (MTBF), mean time to repair (MTTR), and the types and numbers of maintenance personnel required to repair the subsystem. All aircraft, and their associated subsystems, accumulate flying hours. Each aircraft subsystem has a randomly determined flying-hours-to-next-failure value (based on its MTBF). When an aircraft subsystem is deemed failed, the Maintenance Manager queries the appropriate Maintenance Item object, checks the MESL level appropriate for the type of aircraft, and then sets the aircraft status based on aircraft location (home base versus en route) and mission type (home base mission or ensuing leg of existing mission). If the MESL indicates a failed subsystem is not critical for the current mission, the Maintenance Manager sets the aircraft to PMC status. When an aircraft status is set to PMC, the aircraft may be flown on PMC status for appropriate missions, with the failed subsystem(s) to be repaired after return to the aircraft's home base location. Figure 3 provides a graphical depiction of the modeling logic for aircraft status configuration. The MAAF tracks, by aircraft, total time in each status.

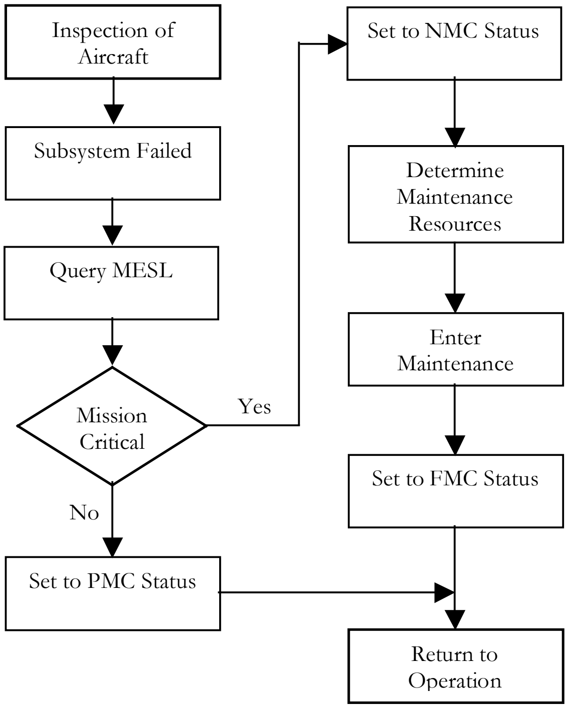


Figure 3. MAAF logic for aircraft status configuration

For MAAF, a Flight Activity object stores mission-based and aircraft-based rules and information. These rules help form a realistic depiction of the mobility system. The mission-based rules trigger when the aircraft is assigned to a mission and govern pre-flight and post-flight activities performed on the aircraft. Preflight activities include fueling of the aircraft, necessary repair checks, launch preparation, and taxi processes. Post-flight activities include taxi processes, post-flight repair checks, and parking. Naturally, aircraft with failures found during repair checks are routed into the maintenance activities. These activities are depicted in Figure 1.

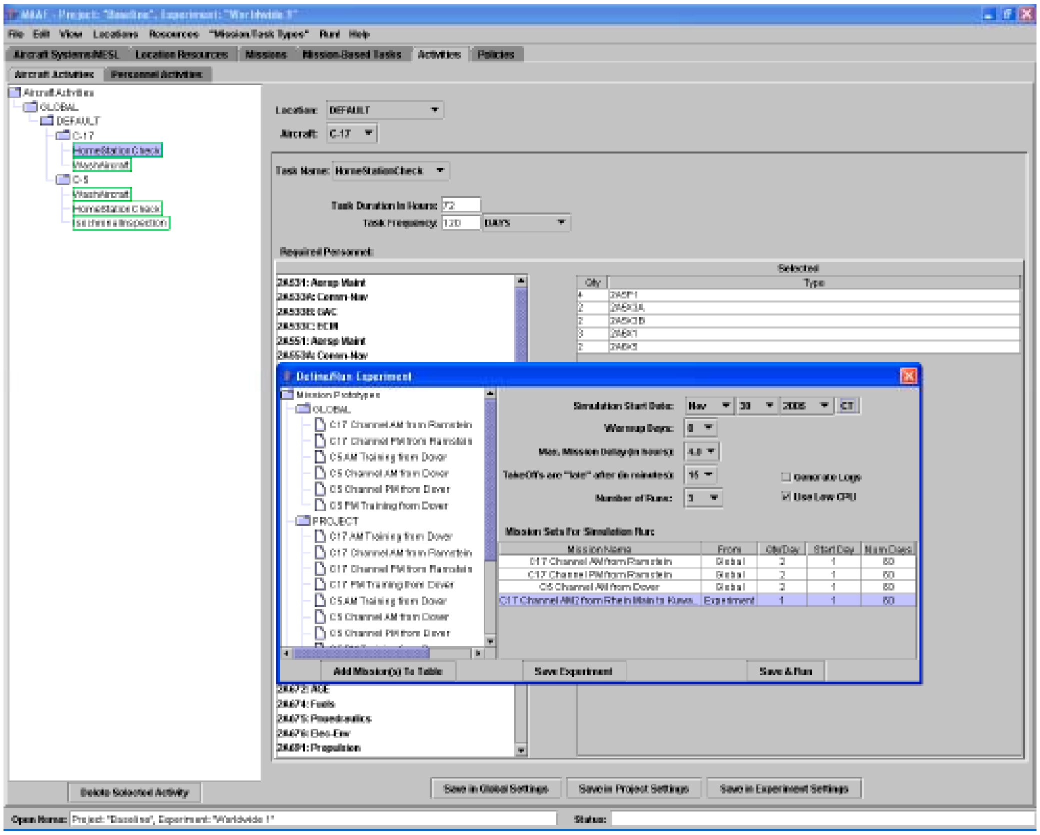
MAAF is data driven. Each simulation instance (bases, routes, infrastructure) is defined via the input data files generated based on user input. Each simulation instance is then further delineated at run time with specific parameter input files. Each airbase and aircraft in a MAAF simulation instance is defined via a separate MAAF interface component. This MAAF interface component, a sample of which is pictured in Figure 4, defines each airbase, each aircraft type and quantity for each airbase, the infrastructure at each defined airbase, and the missions considered within the defined system (and experiment). Pre-stored data include aircraft type specifics and MESL information. This provides the MAAF a high level of general applicability with respect to the analysis of mobility systems. Figure 5 provides a sample interface into the MESL database, in this case for the C-5 aircraft. Note the MESL data is by subsystem and includes MTBF, MTTR, and a link to maintenance resource requirements for that subsystem.

5. MAAF Simulation Experiment

A notional mobility system example was defined and used to test and demonstrate the MAAF simulation. Figure 6 provides a graphic of the modeled system scenario. This scenario considers four airbases in the mobility system: Ramstein AFB, Sigonella IAP, Kuwait City IAP, and Dover AFB. Only Ramstein AFB and Dover AFB own aircraft. Ramstein AFB has five C-17 aircraft, and Dover AFB has twelve C-5 aircraft. The other two airbases function as en route locations in the defined mobility system.

Each airbase is assigned varied levels of maintenance personnel and resources. Personnel work two twelve-hour shifts, and the assignment of personnel to these shifts varies by shift. For purposes of subsystem failure, logistics resource allocation, and MESL consideration, we model the 25 most important subsystems of the C-5 and C-17 aircraft. These subsystems are not listed here but represent those subsystems responsible for the majority of failures for each of the aircraft systems. Both aircraft-based and mission-based rules are included to define the pre-flight and post-flight activities for each of the aircraft at each of the bases.

The experiment consists of four types of mobility aircraft missions, added sequentially to yield Model A through Model D. The missions and the routes of each mission are provided in Table 1. Table 2 contains details on the number of missions of each type, when the



Location: DEFAULT
Aircraft: C-17
Task Name: HomeStationCheck
Task Duration In Hours: 72
Task Frequency: 120 DAYS

Selected

Qty	Type
4	2A5F1
2	2A5X3A
2	2A5X3B
3	2A6X1
2	2A6X5

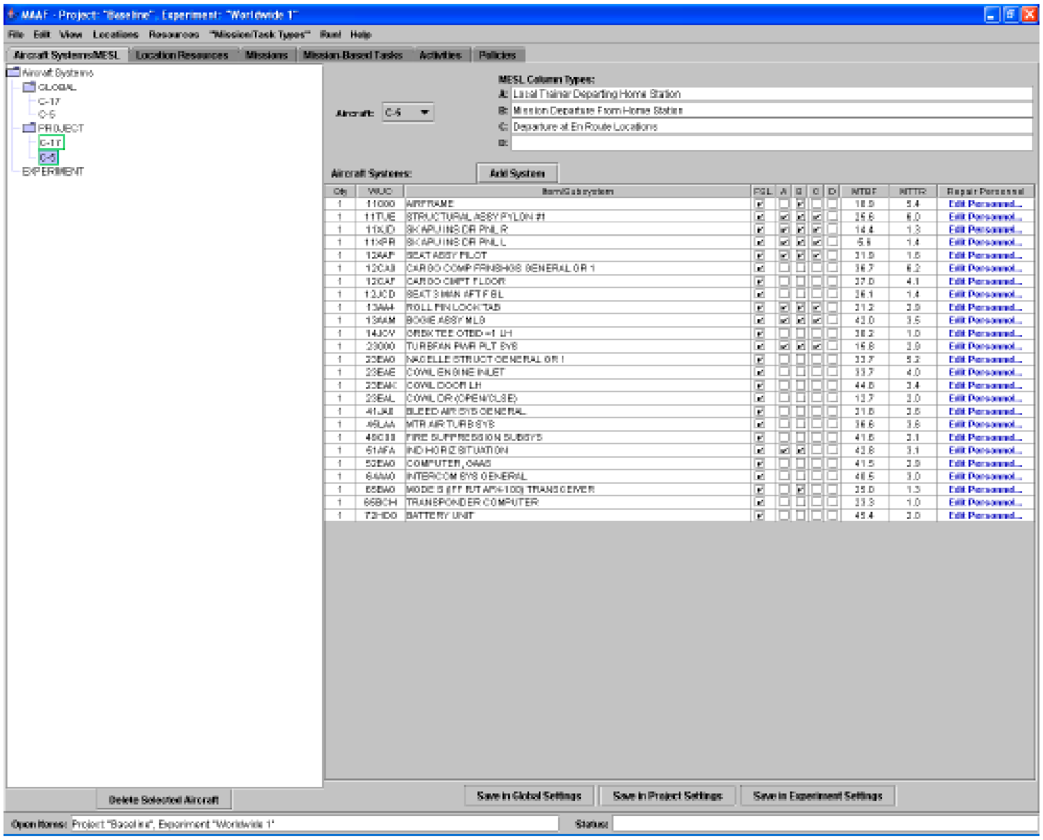
Simulation Start Date: Nov 30 2006
Warmup Days: 0
Max. Mission Delay (in hours): 4.0
TakeOffs are "late" after (in minutes): 15
Number of Runs: 3
☐ Generate Logs
☑ Use Low CPU

Mission Sets For Simulation Run:

Mission Name	From	Qty/Day	Start Day	Num Days
C17 Channel AM from Ramstein	Global	2	1	60
C17 Channel PM from Ramstein	Global	2	1	60
C5 Channel AM from Dover	Global	2	1	60
C17 Channel AM2 from Rhein Main to Kuwa...	Experiment	1	1	60

Open Items: Project: "Baseline", Experiment: "Worldwide 1"

Figure 4. MAAF interface for configuration of mission/scenario parameters



Aircraft: C-5

MESL Column Types:
A: Local Trainer Departing Home Station
B: Mission Departure From Home Station
C: Departure at En Route Locations
D:

Aircraft Systems:

Qty	WUC	Item/Subsystem	FSL	A	B	C	D	MTBF	MTTR	Repair Personnel
1	11000	AIRFRAME	☑	☐	☑	☐	☐	18.9	5.4	Edit Personnel...
1	11TUE	STRUCTURAL ASSY PYLON #1	☑	☑	☑	☑	☐	25.6	6.0	Edit Personnel...
1	11XJD	SKAPUINS DR PNL R	☑	☑	☑	☑	☐	14.4	1.3	Edit Personnel...
1	11XPR	SKAPUINS DR PNL L	☑	☑	☑	☑	☐	5.5	1.4	Edit Personnel...
1	12AAP	SEAT ASSY PILOT	☑	☑	☑	☑	☐	31.9	1.6	Edit Personnel...
1	12CAB	CARGO COMP FRNSHGS GENERAL GR 1	☑	☐	☐	☐	☐	36.7	6.2	Edit Personnel...
1	12CAF	CARGO CMPT FLOOR	☑	☐	☐	☐	☐	37.0	4.1	Edit Personnel...
1	12JCD	SEAT 3 MAN AFT F BL	☑	☐	☐	☐	☐	36.1	1.4	Edit Personnel...
1	13AA4	ROLL PIN LOCK TAB	☑	☑	☑	☑	☐	31.2	3.9	Edit Personnel...
1	13AAM	BOGIE ASSY MLG	☑	☑	☑	☑	☐	42.0	3.5	Edit Personnel...
1	14JCV	ORBK TEE OTBD #1 LH	☑	☐	☐	☐	☐	38.2	1.0	Edit Personnel...
1	23000	TURBFAN PWR PLT SYS	☑	☑	☑	☑	☐	15.8	3.9	Edit Personnel...
1	23EA0	NACELLE STRUCT GENERAL GR I	☑	☐	☐	☐	☐	33.7	5.2	Edit Personnel...
1	23EAE	COWL ENGINE INLET	☑	☐	☐	☐	☐	33.7	4.0	Edit Personnel...
1	23EAK	COWL DOOR LH	☑	☐	☐	☐	☐	44.6	3.4	Edit Personnel...
1	23EAL	COWL DR (OPEN/CLSE)	☑	☐	☐	☐	☐	13.7	3.0	Edit Personnel...
1	41JAB	BLEED AIR SYS GENERAL	☑	☐	☐	☐	☐	31.6	3.6	Edit Personnel...
1	45LAA	MTR AIR TURB SYS	☑	☐	☐	☐	☐	36.6	3.6	Edit Personnel...
1	46C00	FIRE SUPPRESSION SUBSYS	☑	☐	☐	☐	☐	41.6	3.1	Edit Personnel...
1	51AFA	IND HORIZ SITUATION	☑	☑	☑	☐	☐	42.8	3.1	Edit Personnel...
1	52EA0	COMPUTER, GAAS	☑	☐	☐	☐	☐	41.5	3.0	Edit Personnel...
1	64AA0	INTERCOM SYS GENERAL	☑	☐	☐	☐	☐	48.5	3.0	Edit Personnel...
1	65BA0	MODE S (IFF RT APX-100) TRANSCEIVER	☑	☐	☑	☐	☐	25.0	1.3	Edit Personnel...
1	65BCH	TRANSPONDER COMPUTER	☑	☐	☐	☐	☐	23.3	1.0	Edit Personnel...
1	72HD0	BATTERY UNIT	☑	☐	☐	☐	☐	45.4	3.0	Edit Personnel...

Open Items: Project: "Baseline", Experiment: "Worldwide 1"

Figure 5. MAAF interface to access MESL information on C-5 aircraft modeled

missions start within the 40-day window considered, and which missions are contained in each of the four models. Other details not provided here for each input mission include the flying time for each leg of the mission, the scheduled departure and arrival times for each mission on each of the days that the mission is scheduled, and the duration of each mission. For the experiment, we use a five-day warm-up, consider a mission aborted if the mission is more than six hours late, and run the system for a 40-day operational period. Each mission has a scheduled take-off time from the airbase. At the scheduled time, if there is an "idle" aircraft at the home airbase it is assigned the mission. Aborted missions are not rescheduled as we wish to examine overall mission effectiveness as a function of base resources; rescheduling aborted missions would overstate the mission effectiveness measure for the mobility system given the assigned missions.

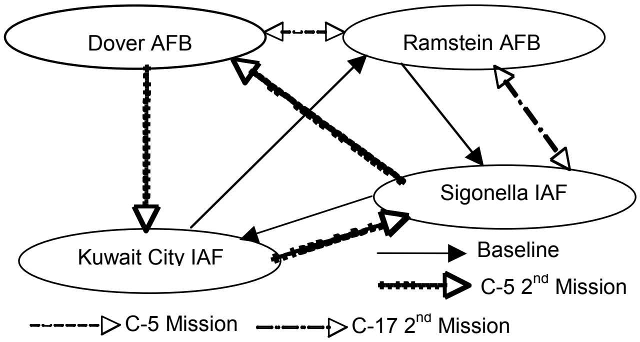


Figure 6. MAAF mission scenario examined

6. Experiment Results and Discussion

The MAAF experiment that follows helps convey the type of information available to the mobility analyst using a MAAF decision support environment. In these results, each replicated model represented 40 days of operations. The measures of interest involve mission capability rate, aircraft status statistics, mission complete statistics, personnel utilization, and aircraft availability. The MAAF accumulates a myriad of data during any simulation run (as do most simulations). The results presented are derived from statistical data accumulated by aircraft (time in status, time at location), by personnel (time assigned to repair processes), and by mission (counts of successful mission launches).

A novel aspect of the MAAF simulation is the modeling of aircraft in PMC status, which is possible since we explicitly model the appropriate MESL data. Figure 7 charts aircraft status results for each of the four models. As the level of flying activity increases, the percentage of aircraft in PMC status increases. This is because there are simply more opportunities for subsystem failure. However, PMC aircraft can in most cases continue with flight operations, a situation past mobility simulation models were unable to accommodate. This new capability with respect to the modeling of PMC aircraft supports better estimates of mobility aircraft operational capability. To highlight this, consider one particular mission of a C-5 aircraft. The C-5 aircraft, after landing at Kuwait City IAP, is found to have a failed subsystem. The Maintenance Manager finds that the failed subsystem is non-essential and changes the aircraft status to PMC. The PMC status does not cancel subsequent legs of the C-5's assigned mission. Thus, the aircraft flies into

Table 1. Description of missions in MAAF simulation

Mission Name	Route
C-17 Channel	Ramstein AFB – Sigonella IAP – Kuwait City IAP – Ramstein AFB
C-5 Channel	Dover AFB – Ramstein AFB – Dover AFB
C-17 2nd Mission	Ramstein AFB – Sigonella IAP – Ramstein AFB
C-5 2nd Mission	Dover AFB – Kuwait City IAP – Sigonella IAP – Dover AFB

Table 2. Missions and their quantity per day

Mission Name	Quantity Per Day	Starting At Day Number	Number of Days	Model A	Model B	Model C	Model D
C-17 Channel	1	1	40	√	√	√	√
C-5 Channel	2	1	40		√	√	√
C-17 2nd Mission	1	21	40			√	√
C-5 2nd Mission	1	21	40				√

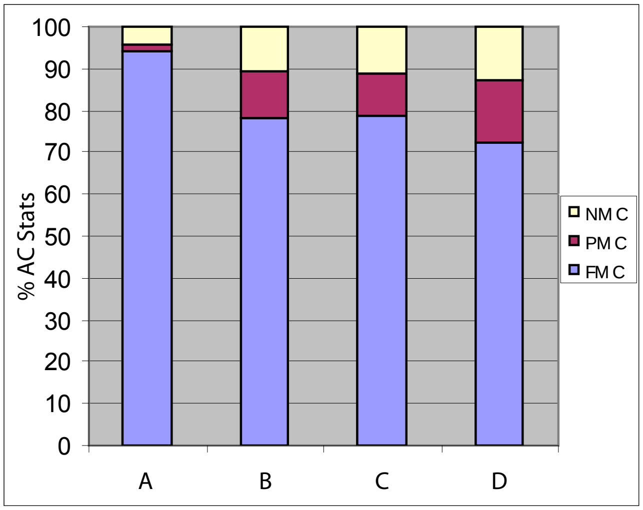


Figure 7. Aircraft (AC) status statistics for models A, B, C, and D as measured by percentage of time in each status condition

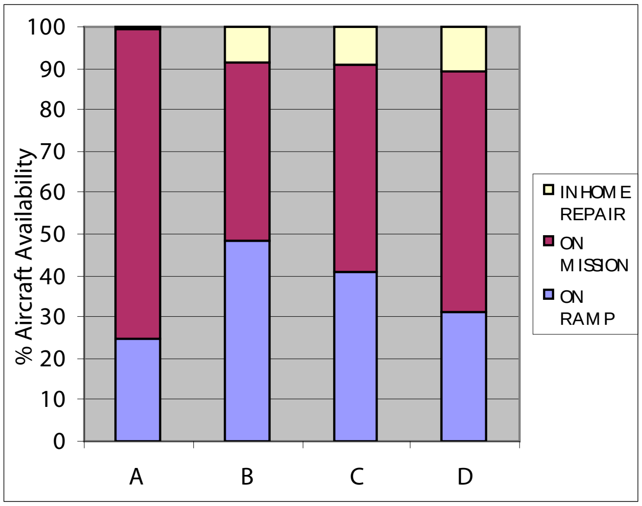


Figure 8. Aircraft availability statistics for models A, B, C, and D as measured by percentage of time in each availability condition

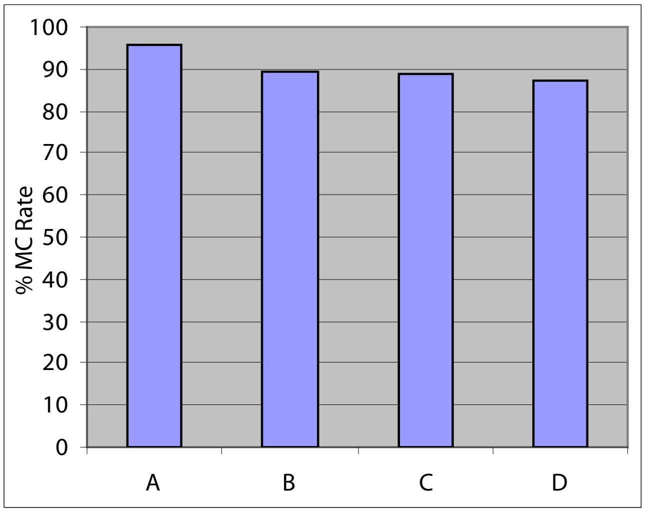


Figure 9. Mission capability (MC) rate statistics for models A, B, C, and D

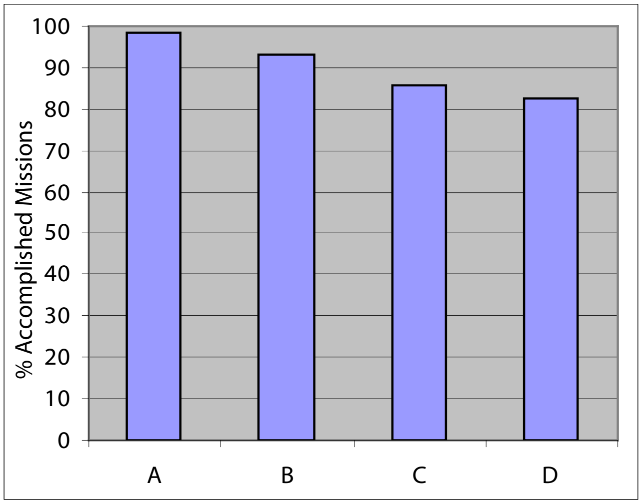


Figure 10. Mission accomplishment rates for models A, B, C, and D

Sigonella IAP on PMC status. Encountering no further subsystem failures, the aircraft leaves on the final leg of its mission returning to its home base, Dover AFB. At the home base, the aircraft status is changed to NMC when it enters the maintenance process where the subsystem is repaired. In a mission lasting 53 hours, the C-5 aircraft was on PMC status for almost 45 hours but completed the assigned mission.

A driving motivation in developing the MAAF is to provide analytical insight into how many aircraft are available for mission tasking. This means tracking aircraft time in maintenance processes, out on missions, and available for assignment ("on the ramp" so to speak). Figure 8 summarizes such information as a percentage of total time available. Aircraft time is broken down into percentages: in home repair, on mission, and on ramp. Once again, as flight operations increase more aircraft subsystem failures occur, increasing aircraft maintenance. The data provides the required insight into how many additional aircraft one could assign to other missions (the *on ramp* percentages).

A very important measure to AMC is the percentage

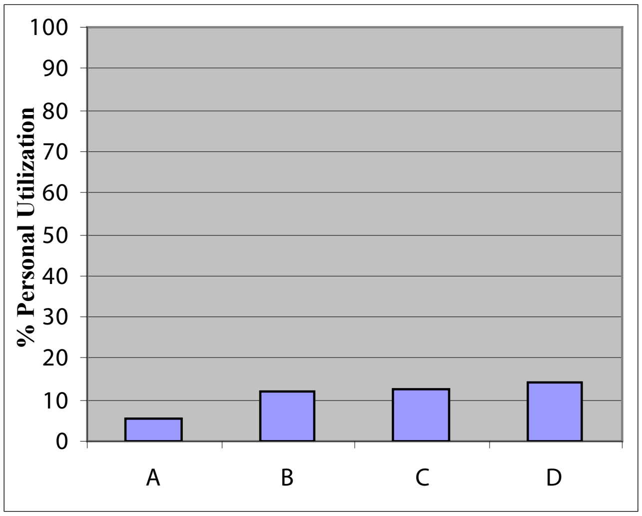


Figure 11. Personnel utilization rates for models A, B, C, and D

of aircraft in mission capable status, or the fleet mission capability rate. This rate is affected by the subsystem failures driving aircraft into NMC status and entry into the maintenance process coupled with the availability of logistics resources to complete any necessary maintenance. MAAF tracks the availability status of each aircraft and aggregates that aircraft data into fleet-wide measures. Figure 9 presents the overall mission capability rates across the four MAAF models considered in our experiment. From the study, it was found that the mission capability rates of the C-17 and C-5 aircraft were 93.45% and 84.68%, respectively. In the model, as the number of missions increases and the corresponding flight activity increases, the mission capability rate decreases but remains at quite acceptable levels. Most importantly, these rates accurately capture PMC status effects.

Mobility analysts are concerned with whether the mobility system can successfully complete assigned missions. Figure 10 provides the percentage of missions accomplished across the four models. As the number of scheduled missions increases and the corresponding flying activity increases, there is increased pressure on the maintenance process to get aircraft ready for flight operations. In a resource-constrained environment, this can cause mission aborts. An excursion on our scenario (see Table 2) involved increasing the missions per day from 1, 2, 1, and 1 to 3, 4, 3, and 4 for models A, B, C, and D, respectively. This added pressure on the limited maintenance resources caused the percentage of missions accomplished to drop to 45.74% (only 45–46 missions of every 100 scheduled are launched).

Our MAAF scenario is not particularly stressing in terms of missions within the system and the level of maintenance actions modeled. The scenario is meant to depict the capabilities and refine the methods of using a MAAF. The high mission accomplishment rates in Figure 10 and the very low personnel utilization rates depicted in Figure 11 support this point. However, the MAAF simulation data does provide a means to examine personnel utilization impacts as a function of system resource changes, which was an intended purpose of MAAF. The simulation provides useful performance measures parsed by airbase and aircraft type.

7. Conclusion

The MAAF simulation model extends the body of knowledge related to the modeling and simulation of logistics systems. Traditional logistic simulation models rely on a static system of bases and routes between the bases. The MAAF simulation demonstrates how a dynamic system definition, embodied within the concept of a MAAF project, is developed and employed. A MAAF system of bases and corresponding infrastructure are created at run time based on user input. The MAAF simulation approach is based on object-oriented concepts of code re-use and object instantiation.

The ability to fly aircraft objects between airbases is an important advancement in airbase logistics modeling via simulation. The aircraft within the MAAF simulation are objects. These objects depart from and arrive at other airbase objects. The MAAF simulation demonstrates the ability to fly potentially heterogeneous aircraft within a dynamically defined system of airbases and have those airbases process transient aircraft in a manner reflective of actual airbase operations.

The notion of non-critical maintenance is a novel, yet important, approach within the domain of logistics simulation. When the simulation model indicates an aircraft object requires repair, that object enters the maintenance process until it is deemed repaired. Within the MAAF model we have defined and demonstrated the ability to represent both fully and partially mission capable status among simulated aircraft objects and thus accurately reflect the ability of actual mobility systems to complete missions with aircraft in less than perfect operational condition.

In actual mobility systems, there are occasions where a particular base within the system is not a full-fledged mobility base. These intermediate bases, called the en route locations, provide a location in which the aircraft can land, refuel, and proceed with the remainder of the mission. These limited capability bases are defined in the MAAF simulation, and these locations process transient aircraft based on the limited capabilities defined for the location.

Finally, the general ability of the MAAF simulation architecture, coupled with a robust analysis function applied to the simulation data, provides a mobility analyst insight into the range of issues about which they are most concerned. Critical among those issues is whether scheduled missions can be completed as assigned with the resources available.

8. References

[1] Schmidt, J. W. "Introduction to Systems, Modeling, and Simulation." In *Proceedings of the 1986 Winter Simulation Conference*, Institute of Electronics and Electrical Engineers, Washington, D.C., 5–16. 1986.

[2] Vincent, P. J., C. S. Allen, R. Hill, and F. Ciarallo. *Mobility Aircraft Availability Forecasting (MAAF) Model.* Final Report to AFRL/HEAL, July 31, 2004.

[3] Carter, W. B., and J. R. Litko. "Simulating the Air Mobility Command Channel Cargo System." In *Proceedings of the 1992 Winter Simulation Conference*, Institute of Electronics and Electrical Engineers, Arlington, VA, 1153–1158. 1992.

[4] Balaban, H. S., R. T. Brigantic, S. A. Wright, and A. F. Papatyi. "A Simulation Approach to Estimating Aircraft Mission Capable Rates for the United States Air Force." In *Proceedings of the 2001 Winter Simulation Conference*, Institute of Electronics and Electrical Engineers, Arlington, VA, 1035–1042. 2001.

[5] Festejo, R. "An Analytical Comparison of the Reduced Footprint of the Modular Aircraft Support System (MASS) vs. Current Aerospace Ground Equipment (AGE)." Master's thesis, AFIT, Wright-Patterson AFB, OH. 2000.

[6] O'Fearna, F. C., R. R. Hill, and J. O. Miller. "A Methodology to Reduce Aerospace Ground Equipment Requirements for an Air Expeditionary Force." *International Journal of Logistics: Research and Applications* 5, no.1 (2002): 75–89.

[7] Narayanan, S., N. L. Schneider, C. Patel, T. M. Carrico, and J. DiPasquale. "An Object-Based Architecture for Developing Interactive Simulations Using Java." *Simulation* 69, no. 3 (1997): 153–171.

[8] Burke, J. F. Jr., R. J. Love, and C. M. Macal. "Modeling Force Deployments from Army Installations using the Transportation System Capability (TRANSCAP) Model: A Standardized Approach." *Mathematical and Computer Modeling* 39, no. 6–8 (2004): 733–744.

[9] Leathrum, J. R., Jr., R. R. Mielk, S. Mazumdar, R. Mathew, Y. Manepalli, V. Pillai, R. N. Malladi, and J. Joines. "A Simulation Architecture to Support Intratheater Sealift Operations." *Mathematical and Computer Modeling* 39, no. 6–8 (2004): 817–838.

[10] Mattock, M. G., J. F. Schank, J. P. Stucker, and J. Rothenberg. *New Capabilities for Strategic Mobility Analysis Using Mathematical Programming.* RAND, MR-296-JS. 1995.

[11] Morton, D. P., R. E. Rosenthal, and L. T. Wang. "Optimization Modeling for Airlift Mobility." *Military Operations Research* 1, no. 1 (1996): 49–68.

[12] Rosenthal, R. E., S. F. Baker, L. T. Wang, D. F. Fuller, D. Goggins, A. O. Toy, Y. Turker, D. Horton, D. Briand, and D. P. Morton. "Application and Extension of the Thruput II Optimization Model for Airlift Mobility." *Military Operations Research* 3, no. 1 (1997): 55–74.

[13] Baker, S. F., D. P. Morton, R. E. Rosenthal, and L. M. Williams. "Optimizing Military Airlift." *Operations Research* 50, no. 4 (2002): 582–602.

[14] Nielsen, C. A., A. P. Armacost, C. Barnhart, and S.E. Kolitz. "Network Design Formulations for Scheduling U.S. Air Force Channel Route Missions." *Mathematical and Computer Modeling* 39, no. 6–8 (2004): 925–943.

[15] McKinzie, K. and J. W. Barnes. "A Review of Strategic Mobility Models Supporting the Defense Transportation System." *Mathematical and Computer Modeling* 39, no. 6–8 (2004): 839–868.

[16] McMillon, Cedric M. SMSgt, USAF. Project Manager, AFLMA/LGM, Maxwell AFB, Gunter Annex AL. Interview, July 20, 2001.

[17] Sentlinger, Billy K. "Optimal Positioning of Naval Precision Guided Munitions." Master's thesis in operations research, Naval Postgraduate School. 2000.

[18] Anderson, Eric B. "Optimizing Ammunition Movement in Support of the U.S. Pacific Fleet's Positioning Plan." Master's thesis in operations research, Naval Postgraduate School. 1998.

[19] Johnstone, D. P., R. R. Hill, and J. T. Moore. "Mathematically Modeling Munitions Pre-Positioning and Movement." *Mathematical and Computer Modeling* 39, no. 6–8 (2004): 759–772.

[20] Crino, J. R., J. T. Moore, J. W. Barnes, and W. P. Nanry. "Solving the Theater Distribution Vehicle Routing and Scheduling Problem using Group Theoretic Tabu Search." *Mathematical and Computer Modeling* 39, no. 6–8 (2004): 599–616.

[21] Barnes, J. W., V. D. Wiley, J. T. Moore, and D. M. Ryer. "Solving the Aerial Fleet Refueling Problem using Group Theoretic Tabu Search." *Mathematical and Computer Modeling* 39, no. 6–8 (2004): 617–640.

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