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THE AIR MOBILITY PLANNER'S CALCULATOR: IMPROVEMENTS, VERIFICATION, AND VALIDATION

THESIS

Frank W. Watson, Jr., Captain, USAF

AFIT/GLM/ENS/03-12

DEPARTMENT OF THE AIR FORCE
AIR UNIVERSITY

AIR FORCE INSTITUTE OF TECHNOLOGY

Wright-Patterson Air Force Base, Ohio

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THE AIR MOBILITY PLANNER'S CALCULATOR: IMPROVEMENTS, VERIFICATION, AND VALIDATION

THESIS

Presented to the Faculty

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In Partial Fulfillment of the Requirements for the

Degree of Master of Science in Logistics Management

Frank W. Watson, Jr., BS

Captain, USAF

March 2003

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THE AIR MOBILITY PLANNER'S CALCULATOR: IMPROVEMENTS, VERIFICATION, AND VALIDATION

Frank W. Watson, Jr., BS
Captain, USAF

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James T. Moore, Lt Col, USAF (Ret) (Chairman)   date

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<div align="right">Frank W. Watson, Jr.</div>

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Abstract

In today's Air Force, we are constantly faced with meeting the mission under limited budget and equipment constraints. Any tools that make completing the mission easier are highly sought after, and rightfully so. The Air Mobility Planner's Calculator (AMPCALC) is one such tool. It gives the mobility planner flexibility in planning by allowing several different situations to be modeled. This paper recommends improvements to the model and provides the verification and validation of the model in an attempt to prove that the model is a useful tool for Air Mobility Command and the United States Air Force.

THE AIR MOBILITY PLANNER'S CALCULATOR: IMPROVEMENTS, VERIFICATION, AND VALIDATION

I. Introduction

Air Mobility Command's primary role in today's Air Force is Rapid Global Mobility, followed closely by Agile Combat Support. Rapid Global Mobility means that we are able to get people and equipment anywhere on the globe quickly. Agile Combat Support means that we do it efficiently. In today's conflicts, we do not have the money or the resources to throw at a problem until it goes away. There is no longer room for waste. Therefore, it falls to the air mobility planner to look at the demands for airlift, prioritize them, and put airplanes against them in order that people and equipment are moved in a timely and efficient manner. Considering that this occurs on a global scale, the task of the planner is immense and constantly changing. One tool that will help the planner is the newly developed Air Mobility Planner's Calculator (AMPCALC).

AMPCALC is a deterministic model that quickly resolves issues such as which airframe to use, flight times, loading and unloading times, ramp space, and virtually everything else having to do with the air mobility process. The model was developed at the Air Force Institute of Technology in 2002 (Pektas, 2002). This research continues that work by making improvements to the model and performing verification and validation of the model. The ultimate goal is to provide AMC with a tool that can be used regularly to quickly and accurately give air mobility planners an idea about how an

air movement should perform and to give them a basic understanding of the levels and timing of throughput.

The model developed by Pektas was well done, but feedback from AMC and potential users have yielded areas for improvement. One improvement is to integrate the four airlift cycles that are currently separate. They were initially designed separately in order to make comparisons of different routes quickly. However, AMC has expressed an interest in having the cycles share resources in order to provide a more realistic picture of an airlift movement. In many cases, passengers and cargo will originate at different locations, travel through the same or different enroutes, and arrive at different destinations. Integrating the cycles should show the feasibility of a movement since it would take multiple routings, force them to share resources, and show how the movement performs. The improved model also matches planes to routes in order to optimize efficiency based on factors such as cargo type and amount, winds, number of stops, and aircraft available.

Additionally, the model is more intuitive for the user. Although Pektas did an admirable job, there are some areas of the model that are unclear and cumbersome to use. The previous method of selecting a route by filling in multiple boxes is changed to an easy to use user form that requests the locations one at a time. The way new locations are input into the model is modified as well; the process is easier and less confusing by guiding the user through the process using forms.

Another aspect of improving the ease of use of the model is modifying the help screens. They are clearer and more concise, and their appearance has changed.

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Previously, the user saw one screen at a time, and had to click a button to see the next screen. The help screens have been adjusted so that the user can scroll through them like traditional windows.

The final improvement is to resolve compatibility issues to ensure the model works on any system. Currently, there are some problems with the model that prevent it from being used across different systems. Since the model is intended to be passed to multiple users and used on deployments, it must be easily transferable.

Chapter II of this thesis includes a literature review of modeling and current airlift models, Visual Basic and Visual Basic for Applications, and verification and validation techniques. Chapter III presents the methodology that was used to improve the model and test it. Chapter IV explains the results of the improvements and the verification and validation. Chapter V presents conclusions and offers areas for future research.

II. Literature Review

Introduction

Mobility modeling is not a new field of research and study. Planners have several resources available to them that provide guidance and procedure when executing a mission. This chapter surveys these resources and the other inputs to the modeling process. A brief overview of general modeling is included. Current airlift instructions and models are discussed to determine the current status of the air mobility modeling process. Visual Basic for Applications is introduced and its benefits and drawbacks are presented. Finally, a review of the verification and validation literature is provided.

Modeling

Modeling is the act of developing a simplified version of a system in order to test a particular part of that system. In virtually all cases, modeling is less expensive and less time consuming than creating the system in its complete, actual form. For instance, it is much easier to test the aerodynamics of a model aircraft wing than it is to build the actual aircraft and test it (Ragsdale, 2001:2). In air mobility modeling, it is much less time consuming to test different airlift options by using a computer model that accurately reflects the important aspects of an airlift mission instead of flying the different options with actual aircraft and crews.

Mathematical models can be divided into three categories: descriptive, predictive, and prescriptive. Descriptive models are used when the relationship of the variables is known, but the values of the variables are unknown. Descriptive models use tools such

as simulation and program evaluation and review technique (PERT). Predictive models are used when the values of the independent variables are known, but the relationship between the variables is unknown. Predictive models use regression, time series, and discriminant analysis. Prescriptive models are used when both the relationship between the variables and the values of the variables are known. They are used in linear programming, network flow programming, integer programming, and nonlinear programming (Ragsdale, 2001:8).

Models can also be classified over time, rate of change, and variation. Static models do not change over time, whereas dynamic models do. Continuous models allow variables to change continuously over a range of values; discrete model variables can only take on particular values and cannot fall anywhere outside those given values. Deterministic models do not account for variation and will give the same answer every time given the same inputs; stochastic models take variation into account and add an element of randomness to attempt to model uncertainty in the system (Kelton and others, 2002:8).

AMPCALC is a prescriptive, static, discrete, and deterministic model. It is prescriptive because the relationships between the variables are known, as are the values of the independent variables. For instance, we know that total mission time is flight time plus ground time, flight time is determined by speed, distance, and other factors, and we know how fast a given airplane flies, how long it must stay on the ground to be refueled, loaded or unloaded, and to meet other requirements. The model is static because it does not take time into consideration. It will not give a different result when given the same

inputs, no matter how much time passes. AMPCALC is discrete because we are dealing with objects that cannot be divided; i.e. we cannot use half of a plane. Finally, AMPCALC is deterministic because variability is not included in the model. Averages are used for those variables that could vary over time, such as wind speeds and ground times in order to give a quick picture of how a mission could be executed.

Current Airlift Models

Air Force Pamphlet 10-1403, Air Mobility Planning Factors, provides broad planning factors for air mobility operations. It allows planners to "make gross estimates about mobility requirements in the early stages of the planning process" (AFP 10-1403, 1998:1). The document provides formulas, planning factors, and examples of different kinds of mobility operations. While the formulas are not difficult to calculate, gathering the necessary data in order to make the computations is very time consuming. For instance, a planner would first have to determine what needed to be moved, what aircraft were available for the operation, the loading/unloading times for the aircraft, the distance to be traveled, block speed for that distance, fuel consumption, crew limitations, etc. While most of the information is available in the pamphlet, attempting to use it by itself to plan a major airlift operation would be a daunting task.

These planning factors are based upon a single cycle. A cycle is defined as an aircraft movement through a route from an origin, or Aerial Port of Embarkation (APOE), through enroutes where the aircraft may receive additional cargo, passengers, fuel, minor maintenance, and a different crew, to its destination, or Aerial Port of Debarkation (APOD), where it is unloaded and returns to its origin. A cycle may include

one or many aircraft and is the basis of several of the calculations used to describe an airlift movement.

In an attempt to automate many of the necessary calculations associated with such an operation, Lt Col David L. Merrill of the Command Analysis Group at Headquarters Air Mobility Command (HQ AMC/XPYS) created the Airlift Cycle Analysis Spreadsheet (ACAS) in 1989. Still in use today, ACAS does in fact make planning a movement much more efficient. However, the program resides completely in one Excel worksheet that is 318 rows x 83 columns. This makes navigation difficult, and although there are some buttons included to help with navigation, trying to find some information can be tricky. Another shortcoming of ACAS is that distances must be determined by using another program and then input into the spreadsheet. Finally, ACAS deals with only two possible airlift cycles. In today's environment, movements will tend to be more complex, so more than two cycles need to be analyzed in order to make the best decision.

AMPCALC was designed to address the shortcomings of ACAS. It incorporates great circle distances that were not calculated by ACAS. Great circle distance is simply the shortest distance between two points on the earth, since the shortest distance between two points on a sphere is not a straight line. A separate spreadsheet called DISTCALC was used to determine Great Circle distances. It also allows for four airlift cycles, but currently they are not simultaneous. AMPCALC also breaks up the single spreadsheet of ACAS into multiple sheets, making navigation easier. This research makes AMPCALC an even better product by enhancing its features.

The Air Mobility Operations Simulator (AMOS) is a simulation of all AMC operations. Currently under development by Emergent Information Technologies, Inc, and Air Mobility Command, AMOS is designed to accurately and dynamically model cargo, passenger, and air refueling scenarios on both the tactical and strategic levels. AMOS uses entities, requirements, resources, command and control, and environments, to build, schedule, and execute missions. Written in C++, AMOS currently operates on Linux systems, with Windows functionality in progress (Duhadway and others, 2001). AMOS is used to test and validate AMPCALC.

Visual Basic for Applications

Visual Basic is an object based programming language developed by Microsoft. Visual Basic is a stand alone product used to create Windows-based programs (Albright, 2001:5). Visual Basic for Applications (VBA), on the other hand, is similar to Visual Basic but runs within Microsoft Office and other software, usually without the user's knowledge. VBA allows the user to increase the functionality of programs by telling the program to execute a certain procedure, also known a macro, when a certain action is taken, i.e. a button is clicked, a value is changed, an option is selected, etc.

VBA is used in the model because it offers the advantages of simplicity, commonality, and accessibility. The VBA language, although not necessarily easy to learn, is certainly not as difficult to learn or use as other programming languages that could possibly be used. Since VBA is an object oriented language, items are easily manipulated after learning relatively simple programming rules. VBA, as a programming language, is ideal for the Air Force (AF) since the service relies heavily on Microsoft

products and Microsoft Excel can be found on virtually every AF desktop computer and laptop. VBA is accessible in that the code can be made available to anyone as long as it is not password protected. This allows the code to be updated and modified as necessary. VBA was also stipulated as the programming language of choice in the Statement of Work provided by AMC.

Verification and Validation

There are several sources that discuss the proper method of verifying and validating a model. Banks, Gerstein, and Searles outline the most frequently used methods in their article "Modeling Processes, Validation, and Verification of Complex Simulations: A Survey." They found five "common threads" that must be used in the modeling process: an initialization phase, an attack plan, creating a detailed design, testing the model, and the operation and maintenance phase (Banks and others, 1987: 13). They found that all of the processes they looked at incorporated verification and validation techniques in every phase, especially in the preliminary ones (Banks and others, 1987: 14). They use the General Accounting Office's (GAO) guidance to modeling as an example: in the twelve steps of the process, only the very last step, "Transfer system to user," does not have verification and validation associated with it (Banks and others, 1987: 14). The same GAO report also gives guidelines on the minimum requirements of evaluating the model. Those guidelines are: documentation, validity (including theoretical validity, data validity, and operational validity), computer model verification, maintainability (including updating and reviewing), and usability (when and how the model should be

used) (Banks and others, 1987: 15). Banks also presents R. E. Shannon's three questions that must be answered while evaluating the model:

1. Does the model adequately represent the real world system?

2. Is the model generated behavioral data characteristic of the real system behavioral data?

3. Does the simulation model user have confidence in the model's results? (Banks and others, 1987: 17).

These principles are put into practice during actual model evaluation, as evidenced by Zaragoza and Hogan and their work on the Integrated Exposure Biokinetic (IEUBK) model for the U.S. Environmental Protection Agency. They outline their verification and validation strategy as:

a. Does the model represent the mechanisms of the modeled system, and are those mechanisms sufficiently understood?

b. How extensive are the data used to create the model?

c. Are the relationships translated into code correctly and free of errors?

d. Can the model be compared with actual data and how reasonable are the results from the model in comparison to the real world behavior? (Zaragoza and Hogan, 1998: 1552)

Balci adds that there are basically two ways of verifying and validating a model: subjectively and statistically. The method ultimately used depends on whether the data are completely observable, partially observable, or completely unobservable (or nonexistent) (Balci, 1987: 21). He claims that modeling is an art and is also situation

dependent (Balci, 1987: 21). Therefore, by designing the methodology using these principles, the conclusions should be in agreement with the majority of the concepts of the verification and validation fields.

With a basic understanding of modeling practices and current airlift models, one can see the usefulness of increasing the functionality of AMPCALC. Using Visual Basic for Applications is an appropriate programming language choice in this case because VBA is widely recognized and is available Air Force and DoD wide. Performing the verification and validation is essential in order to ensure the model accurately reflects the system it is attempting to model. Chapter III explains the approach used in making improvements to the model and conducting the verification and validation of the model. It guides the reader through the methodology of testing the model and provides the basis for interpreting the results.

III. Methodology

Chapter Overview

This chapter explains the theory and procedures used to make improvements and test the validity of AMPCALC. The approach taken to correctly integrate the airlift cycles is discussed and expanded upon in the first section. The steps for verification and validation are outlined in the second section.

Modeling Methodology

The primary purpose of AMPCALC is to give planners a quick, general idea about how an airlift movement will perform; initial questions are "Is it feasible?" and "How long will it take?" AMPCALC attempts to answer these questions as quickly and accurately as possible. However, we must acknowledge that a deterministic model has limitations and can only do so much. This is especially true considering the fact that airlift movements can be very complex. The most basic mission is relatively simple to model. Air Force Pamphlet (AFP) 10-1403, Air Mobility Planning Factors, describes the equations necessary to "make gross estimates about mobility requirements in the early stages of the planning process" (Department of the Air Force, 1998). These equations, which are used in some form in the model and are taken from the ACAS User Manual, include but are not limited to the following equations:

Note: parenthesis ( ) indicate units; brackets [ ] partition mathematical operations; A slash / reflects division and an X multiplication; + and - are used for addition and subtraction, respectively.

1. Number of Cargo Missions = Cargo Requirement (tons) / Average Payload (tons)

2. Number of Passenger (Pax) Missions = [Total Pax - Pax on Cargo Missions] / Pax Capability per Pax Mission

   NOTE: Pax on Cargo Missions = Number of Pax seats available on each cargo mission X Number of Cargo Missions

3. Total Missions Required = Number of Cargo Missions + Number of Pax Missions

4. Round Trip Flying Time (RTFT) = [Leg Dist1 / Block Speed1]+ [Leg Dist2 / Block Speed2]+ ... + [Leg Distn / Block Speedn] for all n legs of the cycle from onload to offload to onload.

5. Average Block Speed = Round Trip Distance (nm) / RTFT (hrs)

6. Total Ground Time (TGT) = Onload Time + [Enroute Time X # of Enroute Stops in Cycle] + Offload Time

7. Cycle Time = Round Trip Flying Time (RTFT) + Total Ground Time (TGT)

8a.   Station Interval (hrs) = Station Ground Time / Station Capability

   NOTE: Station Capability should be expressed in terms of numbers of aircraft a station is capable of handling during the planned ground time at that station. Capability may be limited by ramp space, maintenance, civil engineering, transportation (MHE), refueling, net weight restrictions, base facilities, or command and control. The Station Capability will be the most restrictive of these factors and should be calculated for the station in the cycle with the most prohibitive capability.

8b.   Aircraft Allocation Interval (hrs) = Cycle Time / PAA Allocation (# of Acft)

8c.   Flying Hour Capability Interval (hrs) = [RTFTX24] / [Objective Ute Rate X PAA Allocation]

8d.   Stage Crew Interval (hrs) = [Crew Rest Period - Acft Ground Time] / Number of Stage Crews

   NOTE: This formula is used only when the Number of Stage Crews available is known, or a station's ability to support crews is limited and the number of crews which can be supported is known.

9. Flow Interval (hrs) = maximum of [8a, 8b, 8c, 8d]

10.   Closure (days) = {[Missions Required - 1]X[Flow Interval] + One Way Enroute Time (onload to destination)} / 24   (Merrill, 1989).

As more planes, cargo, passengers, and locations are added, the computation of the above equations becomes more complex. AMPCALC currently models four separate airlift cycles. In order to integrate these cycles to properly reflect a more likely modern-day scenario, significant changes have to be made. Integrating the cycles gives a more realistic view of an airlift operation. In most cases, in order to wage war or support humanitarian activities around the world, there are cargo and passengers at different locations that must share the same number of aircraft and use the same infrastructure. Separate airlift cycles assume that there is nothing else going on in the airlift system. The system includes all other airplanes, crews, and locations that have missions and day to day operations in addition to those being modeled by AMPCALC. While separate cycles still provide an estimate of how a movement might look, a more accurate picture is illustrated when the cycles are integrated.

The first step in integrating the cycles is establishing a common pool of aircraft. A new interface is designed for the user to input the number of aircraft available across all cycles. The routing, cargo, and passenger information is input for each cycle. In most cases, the cycles could differ enough such that maintaining their individual cycle information is necessary. For instance, cycle 1 would have a round trip flying time (RTFT) that is different than cycle 2's which is different than cycle 3's, etc. Since cycle time is driven by RTFT and total ground time (TGT), which also vary by cycle, these numbers must be computed separately as well. Since the majority of formulas depend on results from previous equations, total closure is found by taking the maximum closure times of the individual cycles. In order to ensure the aircraft are properly distributed

between the cycles, an optimization program is developed and solved using Excel Solver. The objective cell is set to minimize the maximum of the four closure times of the four cycles. The problem is constrained by the number of aircraft allocated to the movement. As solver changes the number of aircraft allotted to a given cycle, closure times change. These times should converge to an optimal solution resulting in the shortest closure time for all four cycles.

This approach is tested by running the model with a given number of aircraft in one cycle over a given route with a certain amount of cargo. The results are then compared to the same number of aircraft allotted and tasked to take the same amount of cargo over the same route using all four cycles.

Verification and Validation Methodology

This is a quantitative quasi-experiment, defined as an "experimental approach in which the research does not assign subjects randomly to treatment and control conditions" (Dooley, 2001: 349). Data is collected from AMC and the Air Mobility Operations Simulator (AMOS) on the relevant aspects of the air mobility mission, including number and type of aircraft, flight times, ground times, maximum on ground (MOG) information, etc. The data are then compared to the model output given the same input. This approach traces the data in an attempt to determine how well the model performs. The model diagram is as follows, with the first observation being the inputs to the model and the real world mission planning requirements. The intervention is the model, and the last observation reflects the model output, which can then be compared to the real world and AMOS results.
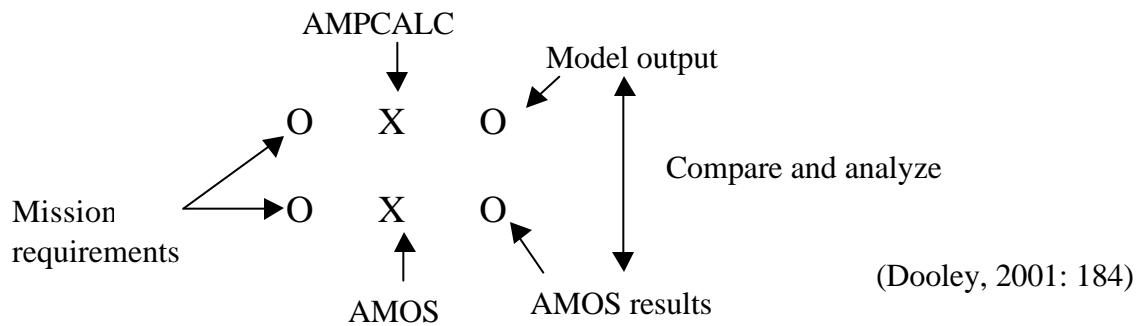
Figure 1. Verification and Validation Methodology Model

The verification and validation procedures used on the AMPCALC closely mirror those done by Zaragoza and Hogan in their validation and verification of the Integrated Exposure Biokinetic (IEUBK) model (Zaragoza and Hogan, 1998: 1552). Specifically, these procedures include:

- Review the model documentation

- Compare the equations in the model with the theory behind the model

- Verify the Visual Basic for Applications code for completeness, accuracy, and efficiency

- Use a math software program (such as MathCad) to validate equations and results

- Conduct analysis of model output and actual real world missions to determine how accurately the model performs

- Consult the Air Mobility planning experts at AMC for their feedback on the appropriateness and validity of the model

- Consult with experts from AFIT to validate the analysis

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- Ensure the model meets US Air Force guidelines for model development and structure

- Recommend improvements for ease of use and user interface

- Investigate the appropriateness of adding variability to the model (probabilistic modeling)

Upon completing the above steps, a very good indication is available on how effective and accurate the AMPCALC really is, and how useful it might be to the Air Mobility Command.

IV. Analysis and Results

Chapter Overview

This chapter discusses the results of the improvements and modifications to the model and the results of the verification and validation of the model.

Improvement Results

The model now includes the option to integrate the cycles. An Excel Solver routine is written in VBA and is accessed via a button on the Aircraft Allocation sheet. Pressing the "Integrate Cycles" button brings up a user form that allows the user to input the number of available cargo and passenger aircraft that will be allocated across all four cycles. Pressing the "Compute Closure" button at the bottom of the user form closes the dialog box and launches the solver routine, which allocates the aircraft over the different cycles and routes in order to achieve the fastest closure time for the system. The problem is bound by ensuring the number of aircraft allocated does not exceed the number available and by ensuring the cargo and passengers that must be moved are indeed transported from their origin to their destination. At this time, the solver routine does not produce an optimal answer because the problem, as formulated, is not linear. Attempts to solve as a nonlinear problem also did not succeed; in those instances, Solver encountered an error in the problem and could not find a solution. Solver should be able to handle this optimization. There are 88 variables, or changing cells, which is well under its 200 decision variable limit. Also, there are only 30 constraints, which is also well under Solver's limit of 100 constraints (Frontline Systems, 2000: 9).

A convenient byproduct of optimizing closure times is that planes are assigned to routes that are better able to take advantage of a particular aircraft type based on properties such as cargo type and amount, winds, distance, block speed, and number of stops. Unfortunately, since the optimization itself does not work at this time, this feature is also not functioning. However, upon successful implementation of the Solver optimization, the air mobility planner will have a better idea about where to position assets to maximize efficiency.

The new Routing screen has a "Change Routing" button above each of the cycles. Clicking on this button brings up a user form that allows the user to create or change the current routing of a given cycle. Pressing the button above the respective cycle column will default to changing that column's entries, but the user is able to choose which cycle to modify by using the option buttons at the top of the form. The user also has the option to completely clear the current routing and start from scratch by pressing the "Clear Routing" button on the left side of the form. In the middle of the form, a VBA combo box is used to select a location, which can be found by using either the name or ICAO code, which is determined by another set of option buttons to the right of the combo box. Once a location has been chosen, the user must assign the location to be either the origin, enroute, or destination by pressing the respective buttons located below the combo box. As enroute locations are added, additional options appear next to the enroute location. A "Change" button appears next to each entry that allows the user to modify that location. Pressing the "Change" button clears that position in the routing and allows the user to choose another location in its place. Any empty locations in the enroute column are

automatically filled in with the previous entry's location, indicating that no travel is taking place between those two points. A textbox appears for the user to input average wind conditions to that location. A combo box appears for the user to select the stop type at that location. After updating the routing, combo boxes are used to determine what kind of stop is assigned to the location. Previously, the user had to manually enter a number between one and five in order for the model to determine if the location was an onload, a navigational waypoint, an enroute, an offload, an engine running offload (ERO), or another non standard stop type. The user now simply selects what kind of stop takes place at a location by choosing that option from the combo box to the right of the location. Similarly, Yes/No option buttons appear to the right of the combo boxes to indicate whether or not crews are staged at the enroute location. The user can now see at a glance what kind of stop occurs and if crews are staged at a given location. When the route is complete, the user presses the "Update Routing" button. This button fills in any blanks left by the user and places the values in their respective positions on the routing input page. This approach results in the ability to make modifications to routes more quickly and easily and should be much easier for the user to understand. Buttons have also been added that allow the user to simply press "Yes" or "No" to the query of whether the routes are used for one way traffic or if traffic is moving in both directions. Pressing "Yes" tells the model that the locations must deal with airlift coming from both directions, whereas pressing "No" tells the model the airlift is only going in one direction through the route.

Figure 2 illustrates the new routing form.

Figure 2. The New Routing User Form

The model also has a dialog box that allows the user to add new locations to the

ICAO list. Pressing the "Add New Location" button on either the Routing or Distance

Calculation sheet displays the "Add New Location" window, which allows the user to

input the necessary items associated with a location. These items include the name,

ICAO, region, latitude, and longitude of a new location. The user selects North/South for

latitude and East/West for longitude with option buttons. The region selection is a combo

box that lists the regions currently included in the ICAO list. The user can simply choose

from the list or input a new region identifier. Pressing the "Add Location" button adds

the information to the ICAO list, formats the entries properly, and sorts the list by ICAO

and by location name. Figure 3 illustrates the add location dialog box.

Figure 3. The Add New Location User Form

The information screens designed to give users background and instructions on

each of the sheets have been improved. Users should feel more comfortable with the

more traditional windows dialog box with scroll bars when appropriate and an "OK"

button at the bottom of the screen that hides the information box when pressed. In

addition, the information screens have been edited for readability and incorporate changes that have been made.

Buttons have been added throughout the model in lieu of forcing the user to input some kind of code in order to get the model to perform in a particular way. Examples include "On" and "Off" buttons for the Mission Capable rate factor on the Aircraft Standard Planning Inputs Factors sheet, "AMMP" and "DS" buttons on the Aircraft Ground Times Input sheet which tells the model to use either Air Mobility Master Plan or Desert Storm ground times, and "No Limit" and "Limit" buttons on the Aircrew Call-up and Limits sheet, which determines whether or not crews are a limiting factor in an airlift movement. All of these improvements make the model easier to use by showing the user what can and cannot be changed and allows for easier analysis of the effects on closure of the different inputs.

Since the model is intended to be passed to multiple users and used on deployments, it must be easily transferable. Improvements in this area are continuing as the model is subjected to various different machines with different versions of Windows, Excel, VBA, and Excel Solver. Thus far, most compatibility issues have been solved by declaring variables in the different subroutines of the VBA code. Previously, variables were not defined prior to their use and would cause the VBA code to produce an error when it encountered a variable with which it was not familiar. The model was tested on several different systems in and around the AFIT community and has met with success thus far. In addition, a group of AFIT students was tasked to test the model in order to find compatibility issues. All issues raised by the group have been solved.

Verification and Validation Results

In order to verify and validate AMPCALC, the following questions proposed in the literature review and the methodology are answered below.

1. Does the model adequately represent the real world system? In many respects, the model does adequately represent the real world system. Many factors that affect an airlift cycle are incorporated into the model. Mission capable rates, crew limits, MOG considerations, number of aircraft available, actual carrying capacities of cargo and passengers, different block speeds based on distance and those based on standard planning factors are all included. However, there are some limitations; as a deterministic model, it does not take the variability that exists in any real world system into account. It also allows the user to fly anywhere in the world when real world constraints may not permit this. The output of the model is only as good as the inputs, and the better the inputs, the more realistic the outputs will look.

2. Is the model generated behavioral data characteristic of the real system behavioral data? The data generated by the model are characteristic of the real system behavioral data. When dealing with airlift movements, ground times, block speeds, and closure times are used to determine how effective a movement will be. The model's ability to use the planning factors that are input to the model accurately produce these desired results.

3. Does the simulation model user have confidence in the model's results? The model currently produces reasonable responses when given realistic input. The formulas

used in the model have been validated and the user should have confidence that the model works as intended.

4. Can the model be compared with actual data and how reasonable are the results from the model in comparison to the real world behavior? The model results can and have been compared with actual data from the Air Mobility Operations Simulator (AMOS) and are acceptable. As long as the user provides appropriate input to the model, the results will generally be an 83% solution. The results of actual comparisons are included below.

5. Does the model represent the mechanisms of the modeled system, and are those mechanisms sufficiently understood? The model accounts for the majority of factors that influence an airlift movement, including number and type of aircraft, cargo and passenger limitations of the aircraft, loading and ground times, adjusted flying times based on distance and airspeed, maximum on ground limitations, crew limits, and mission capable rates. The model does not, however, take into account the possible variability that can occur over the time the movement is taking place. Many of the factors listed above may change. The number of aircraft may be reduced due to higher priority missions. Loading and ground times are based on averages, which may or may not hold true throughout the duration of the movement. Winds that will affect airspeed and closure time may change. Maximum on ground numbers may not be valid throughout the duration as the model does not account for all possible traffic that passes through a particular location. Mission capable rates are subject to change as well.

6. How extensive are the data used to create the model? The data used to create the model was obtained from several sources, including Air Force Pamphlet 10-1403, Air Mobility Planning Factors and the Airlift Cycle Analysis Spreadsheet. These sources provided the necessary information to accurately model an airlift movement, to include equations to properly model airspeed, closure time, flow interval times, and several other interactions that are used in the model. AFP 10-1403 provided the planning factors that are used for ground times, loading/unloading times, servicing times, crew limits, and mission capable rates.

7. Are the relationships translated into code correctly and free of errors? One benefit of using Excel is that the equations are easy to set up within the model. VBA also allows additional control over the model and permits the user to use the equations easily and more efficiently because they are embedded in the worksheets. VBA also allows the model to make difficult functions, such as calculating great circle distances, transparent. In this case, the equations necessary to determine the distance between two points were put into a VBA function routine, which is then called by name from the model using the latitude and longitude of the two locations.

The methodology introduced the following list of actions to be completed in order to insure validity. The results are listed below.

1. Review the model documentation. The model's documentation is included within the model in the form of help screens. These screens were revised and updated for both clarity and accuracy. They give an accurate and informative picture of the capabilities of the model.

2. Compare the equations in the model with the theory behind the model. The equations used in the model match those given in AFP 10-1403 and ACAS. These equations have been validated for accuracy.

3. Verify the Visual Basic for Applications code for completeness, accuracy, and efficiency. Several changes were made to the VBA code in the interest of completeness and efficiency. One instance involved replacing over 20 pages of code that looped through the location list in order to find a match to a given location in order to find the location's latitude and longitude. There were several shortcomings with the previous version of the program. First, it took an inordinate amount of time for the program to loop through the 2100+ locations in the model. Secondly, there was a loop set up for each location, meaning there were 44 instances of the same code. Finally, the loops did not allow for locations to be added to the model. Eliminating the redundant code and replacing it by using Excel's built-in VLOOKUP function in the cells where the information was needed neatly solved this issue.

A second instance where the code was modified dealt with the Great Circle Distance calculation. The first version of the model used a separate subroutine each time a distance had to be calculated between two points. The actual code to perform the calculation is approximately half a page long. Since there are four cycles, there were over 40 repetitions of this code. Several pages of code were eliminated by creating a function subroutine that can be called from both the distance calculation sheet and the routing sheet. The function uses the latitude and longitude of the locations in order to find the distance. Another benefit of this approach is that the function is available in the

Excel menus as a user defined function that can be easily found and exported for other uses.

4. Use a math software program to validate equations and results. MathCAD 2001i Professional was used to replicate the equations used in the model and validated the results of the equations. All results were within 3% of the model's output. The MathCAD templates used can be found in Appendix 1. The great circle distance calculation was also compared with a similar type calculator found on the internet at http://www.gb3pi.org.uk/great.html. While the calculator on the website produces answers in miles and AMPCALC produces answers in nautical miles, conversion factors were used to find common units for the purpose of comparison. The distance between 40°1" north latitude, 74°34" west longitude and 50°26" north latitude, 7°36" east longitude was calculated. As Table 1 shows, the percent difference between the two methods is less than 0.1%.

Table 1. Comparison Results between AMPCALC and gb3pi Distance Calculators

Method	Distance	Conversion factor	Distance	% Difference
AMPCALC	3348 nm	1.853 km/nm	6203.844 km	
gb3pi	3853 mi	1.609 km/mi	6199.477 km	.07

5. Conduct analysis of model output and actual real world mission results to determine how accurately the model performs. AMPCALC results were compared with the AFMTest data in AMOS. Tests were performed on AMOS to ensure the level of fidelity necessary for comparison. The model was run using 1, 5, 10, and 20 repetitions with different random seeds. As the number of repetitions increased, the 95% confidence

intervals around the mean decreased as expected, and led to the conclusion that more than one repetition would not be necessary in order to maintain the desired level of accuracy. Table 2 presents this information.

Table 2. Means and Confidence Intervals for Multiple AMOS Repetitions

Number of Repetitions	Mean Closure	95% CI Lower	95% CI Upper
1	38	n/a	n/a
5	37.8	37.24	38.36
10	37.9	37.67	38.13
20	37.8	37.61	37.99

AMPCALC was compared to AMOS using four different scenarios. All of the scenarios are part of the AFMTest that is included with and used to test AMOS. Each scenario uses a piece of the overall movement required by the AFMTest scenario. In each case, the cycle under investigation was modified to include only those aircraft and requirements that were to be moved from one APOE to one APOD. This required modifying the input files in AMOS, particularly the AirUnit and Requirements files. The AirUnit file lists all of the aircraft that are available to the simulation. The file was modified to include only those aircraft that were allocated to the cycle, and the rest of the aircraft were given a zero balance. The Requirements file lists all of the cargo and passenger requirements that need to be moved from an APOE to an APOD. All requirements that were not associated with the APOD/APOE pair under investigation were deleted. These modifications allowed for a better comparison between AMOS and AMPCALC.

The AFMTest is a hypothetical, unclassified scenario that takes place in southwest Asia. The APOD for the majority of cargo and passengers is Kuwait (OKBK). Therefore, three of the four scenarios use OKBK as the APOD in order to have enough throughput to warrant investigation. The APOEs for those scenarios are Dover Air Force Base, Delaware (KDOV), Robert Gray Army Air Field, Fort Hood, Texas (KGRK), and Jiyanklis New, Egypt (HE8X). The fourth scenario uses Miramar, Marine Corps Air Station, California (KNKX) as the APOE and Shaikh Isa, Bahrain (OBBS), as the APOD. The results of these comparisons are shown in Table 3.

Table 3. AMPCALC and AMOS Scenario Comparison Results

Routing	Aircraft	Requirements (stons)	MOG	AMPCALC Closure (days)	AMOS Closure (days)
Dover Barajas (Madrid) Kuwait	19 C-5A 20 C-17 20 WBC 15 WBP	0 Outsize 87 Oversize 4,426 Bulk 469 Pax	15 at OKBK	4.76	4.11
Robert Gray AAF Barajas Kuwait	10 C-5A 20 C-17 10 WBC 10 WBP	2,456 Outsize 2,802 Oversize 321 Bulk 8,185 Pax	15 at OKBK	11.04	8.15
Logan Frankfurt Jiyanklis New (Egypt) Kuwait	5 WBC 20 WBP	1 Outsize 5 Oversize 132 Bulk 10,226 Pax	3 at HE8X	4.81	3.95
Miramar Dover Moron Shaikh Isa (Bahrain)	40 C-5A	293 Outsize 1406 Oversize 184 Bulk 1,347 Pax	6 at OBBS	6.78	6.06

As the table shows, the differences between AMPCALC closure times and AMOS closure times are relatively small. Percent differences were calculated and are listed in Table 4.

Table 4. Percent Difference and Percent Accurate Comparison Results between
AMPCALC and AMOS

Origin	Destination	AMPCALC	AMOS	% Difference	% Accuracy
KDOV	OKBK	4.76	4.11	13.7	86.3
KGRK	OKBK	11.04	8.15	26.2	73.8
HE8X	OKBK	4.81	3.95	17.9	82.1
KNKX	OBBS	6.78	6.06	10.6	89.4
Total				17.1	82.9

As the table shows, AMPCALC closure time is within 17% of the AMOS closure time on average.

6. Consult the Air Mobility planning experts at AMC for their feedback on the appropriateness and validity of the model. Unfortunately, due to current world events, AMC/XPY has not been able to devote the time and manpower to assist in this endeavor as much as they would have liked. However, the model has been given to them for their review and use, and their feedback will be included if further revisions of the model are accomplished.

7. Consult with experts from AFIT to validate the analysis. Since there are not many analysis tools available to compare the results of a simulation with the results of a deterministic model, AFIT faculty and AMC/XPY analysts agreed that the analysis performed was accurate and appropriate.

8. Ensure the model meets US Air Force guidelines for model development and structure. Air Force Instruction 16-1001, Verification, Validation, and Accreditation (VV&A) implements Air Force Policy Directive 16-10, Modeling and Simulation Management, and outlines the responsibilities of agencies developing and implementing

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models and simulations (M&S). At this point in time, the AFI does not govern the

development of AMPCALC because it does not meet the criteria of a major model and

simulation. Specifically, AMPCALC is not an element of a federation of models and

simulations, its application does not involve safety of life, and its development does not

involve the commitment of significant DoD resources. Should any of those conditions

change, the model would be subject to the provisions of AFI 16-1001, and AMC would

have to appoint a Verification and Validation Manager to the model to ensure the

requirements of the AFI are met (AFI 16-1001). In its current state, AMPCALC should

have little difficulty following the guidelines should the need arise.

9. Recommend improvements for ease of use and user interface. A mobility

modeling class at the Air Force Institute of Technology was given the model and

instructions to provide feedback on ease of use and other issues. Future feedback will be

incorporated if improvements on the model continue to be made.

10. Investigate the appropriateness of adding variability to the model

(probabilistic modeling). At this point, introducing variability to this model would

probably be counter-productive. The main objective of the model is to give planners a

quick idea about how an airlift movement will perform. Introducing variability may add

additional, unnecessary complexity to the model that the casual user would not

appreciate. Introducing variability also means that several repetitions would have to be

performed before a reasonable answer can be reached. This detracts from the model's

goal of being a quick look type of tool. Finally, in light of the current, ongoing

development of AMOS, which has the sole purpose of modeling the variability of the airlift system, adding variability to AMPCALC is not recommended at this time.

In conclusion, the improvements to the model make the model run more smoothly and reliably, allowing for wider distribution and use of the model. The verification and validation efforts offer encouraging evidence that the model sufficiently represents the real world system and allows planners to quickly analyze an airlift mission and arrive at a reasonable assessment of how it will perform. The next chapter discusses the limitations and conclusions of this endeavor.

V. Conclusions and Recommendations

In the process of improving and validating the model, several limitations were discovered. The first and most significant limitation was that AMC/XPY was not as available as the researcher would have hoped. Unfortunately, due to unforeseen world events, issues of greater importance required their attention. Ultimately this meant that feedback or comparison data was not available to run the model against, and therefore the results are based on comparisons to theoretical and simulated data. Another dilemma encountered was that some of the data that possibly could have been used for comparison was classified. In order to keep this thesis unclassified, that data was not provided or used.

Another limitation existed with the Air Mobility Operations Simulator (AMOS), in that there were several problems getting it installed correctly, and once installed, was difficult to manipulate. Additionally, the installation delays limited its availability. AMOS is continuously being updated, and not having the latest version impeded the progress of the comparisons. One particularly troubling problem was the inability to modify the data flat files that serve as inputs to the simulation. Comparisons were made using pieces of the very large, complex deployment. The Reports Tool of AMOS was also having problems by not including the names of the Aerial Ports of Embarkation (APOE) in the reports it generated, making it exceedingly difficult to determine from where the cargo was coming.

The model itself has its own limitations. There are many factors involved in an airlift mission that a model such as this simply cannot incorporate. For instance, the

model does not take limited operating hours, special operating conditions, quiet hours, and the like into consideration. It limits the entire cycle to the minimum MOG of one location, even though other bases would not be constrained in such a manner in a real world situation. It also assumes that all of the cargo and passengers are available to move at time zero. This is not necessarily a realistic assumption. Of course, these drawbacks can also be considered strengths: if the model included every factor that affects an airlift cycle, it would not be as simple to operate and would take much longer to produce a result.

Unfortunately, there were improvements that the researcher set out to do that could not be accomplished. Integrating the airlift cycles did not come to fruition. This happened as a culmination of several factors: while the formulation of the model appeared to be linear, Excel Solver indicated that it was not. In addition, Excel Solver was not working properly when applied to the model. For instance, its dialog box would close when the "Add Constraint" button was pressed. The formulation met the criteria necessary for Solver to work, but it simply would not. The best explanation for this occurrence is that there are so many interactions between the number of aircraft allotted to a cycle and closure time that Solver was losing track somewhere and would result in a nonlinear answer. Furthermore, some Excel functions were not operating as they should have been. For instance, whenever the user tries to use the "Save As" command from the "File" drop down menu, Excel would experience an error and close. Also, when trying to manipulate certain parts of the model, particularly the location data, Excel would experience an error and close.

Finally, there was significant difficulty associated with following on with someone else's code, even in the relatively simple language of Visual Basic for Applications. Differing experience levels with programming and different logic paths proved to be noteworthy impediments to producing the best possible code. Programming is sometimes considered an art, and it would be almost unheard of for one artist to pick up and finish another's work once started.

Despite these limitations, however, some progress was made. Even with the differences in programming experience and logic, some advances did result in significant model improvement. Several pages of code were eliminated and the model was streamlined. Compatibility issues were addressed and resolved. The model is easier to use and more intuitive for the user that does not have daily exposure to this kind of material due to the inclusion of better information screens, user forms, and selection buttons. The model provides a good, quick look at how an airlift movement might perform, which will allow airlift planners a starting point before committing resources to an endeavor that probably will not work. The verification and validation shows the model is an appropriate approximation of what really happens. All things considered, the AMPCALC can and should be a valuable tool for mobility planners.

As with all endeavors, however, there is still room for improvement. Areas for further study include readdressing the cycle integration issues, performing more comparisons with real and simulated data, and improving the code to make it more efficient. These avenues are happily offered to those who might follow in my footsteps.

Appendix 1. MathCAD Equation Verification

1. Number of Cargo Missions = Cargo Requirement (tons) / Average Payload (tons)

2. Number of Passenger (Pax) Missions = [Total Pax - Pax on Cargo Missions] / Pax Capability per Pax Mission

    NOTE: Pax on Cargo Missions = Number of Pax seats available on each cargo mission X Number of Cargo Missions

3. Total Missions Required = Number of Cargo Missions + Number of Pax Missions

4. Round Trip Flying Time (RTFT) = [Leg Dist1 / Block Speed1]+ [Leg Dist2 / Block Speed2]+ ... + [Leg Distn / Block Speedn] for all n legs of the cycle from onload to offload to onload (for C-5) (uses corrected distances).

5. Average Block Speed = Round Trip Distance (nm) / RTFT (hrs)
(uses actual distances)

6. Total Ground Time (TGT) = Onload Time + [Enroute Time X # of Enroute Stops in Cycle] + Offload Time

7. Cycle Time = Round Trip Flying Time (RTFT) + Total Ground Time (TGT)

8a.   Station Interval (hrs) = Station Ground Time / Station Capability

8b.   Aircraft Allocation Interval (hrs) = Cycle Time / PAA Allocation (# of Acft)

8c.   Flying Hour Capability Interval (hrs) = [RTFTX24] / [Objective Ute Rate X PAA Allocation]

8d.   Stage Crew Interval (hrs) = [Crew Rest Period - Acft Ground Time] / Number of Stage Crews

9. Flow Interval (hrs) = maximum of [8a, 8b, 8c, 8d]

10.   Closure (days) = {[Missions Required - 1]X[Flow Interval] + One Way Enroute Time (onload to destination)} / 24

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Vita

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14. ABSTRACT

In today's Air Force, we are constantly faced with meeting the mission under limited budget and equipment constraints. Any tools that make completing the mission easier are highly sought after, and rightfully so. The Air Mobility Planner's Calculator (AMPCALC) is one such tool. It gives the mobility planner flexibility in planning by allowing several different situations to be modeled. This paper recommends improvements to the model and provides the verification and validation of the model in an attempt to prove that the model is a useful tool for Air Mobility Command and the United States Air Force.

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