Optimizing Route Planning for C-17 Operations Utilizing Artificial Neural Networks for Weather Prediction

THESIS

Garrett A. Alarcon, 1st Lieutenant, USAF

AFIT-ENS-MS-20-M-

DEPARTMENT OF THE AIR FORCE
AIR UNIVERSITY

AIR FORCE INSTITUTE OF TECHNOLOGY

Wright-Patterson Air Force Base, Ohio

AFIT-ENS-MS-20-M-

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Presented to the Faculty

Department of Operational Sciences

Graduate School of Engineering and Management

Air Force Institute of Technology

Air University

Air Education and Training Command

in Partial Fulfillment of the Requirements for the

Degree of Master of Science in Operations Research

Garrett A. Alarcon, B.S.

1st Lieutenant, USAF

March 2020

AFIT-ENS-MS-20-M-

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Garrett A. Alarcon, B.S.
1st Lieutenant, USAF

Committee Membership:

Lt Col A.J. Geyer, Ph.D.
Chair

TBD
Reader

Table of Contents

Page

List of Figures v

List of Tables vi

I. Introduction 1

1.1 Background 1
1.2 Overview 2
1.3 Problem Statement 3

II. Literature Review 4

2.1 Overview 4
2.2 Weather Models 4
2.3 Weather Factors 5
2.4 Artificial Neural Networks 6
2.5 Shortest Path Problem 6

Appendix A. Relevant Theses 7

Bibliography 8

List of Figures

Figure Page

List of Tables

Table Page

OPTIMIZING ROUTE PLANNING FOR C-17 OPERATIONS UTILIZING ARTIFICIAL NEURAL NETWORKS FOR WEATHER PREDICTION

I. Introduction

1.1 Background

The Department of Defense (DoD) has an obligation to the American people to be stewards of their tax dollars in all defense related spending. As such, the DoD is always searching for ways to minimize spending while also increasing combat capabilities, military readiness, and operational effectiveness. Aircraft are an integral part of the United States Air Force (USAF) and by its very nature, fulfilling these goals incurs a substantial cost for procuring and consuming fuel. From the 2019 fiscal year budget for the DoD, $24 billion was requested for fuel consumption with $6.6 billion going to operations and $4.5 billion going to transportation [1]. The USAF consumes around half of this budget for aviation fuel with majority of it being used by Air Mobility Command (AMC), a major command (MAJCOM) within the USAF structure [2]. Of the many aircraft within the AMC inventory, the C-17 fleet represents the primary aircraft responsible for global transportation and cargo, and as such consumes the largest amount of the aviation fuel [3]. Increasing efficiency in fuel consumption within this fleet can have an immense impact on cost savings for the USAF, and the DoD as a whole.

1.2 Overview

There are a multitude of ways to address increasing efficiency in fuel consumption among C-17s. This study focuses particularly on headwind and temperature predictions in the upper atmosphere relating to mission planning for C-17 operations. Having accurate predictions for the varying spatial regions of the atmosphere will enable mission planners to develop the most fuel efficient route from origin to destination. Thereby being able to optimize altitude and flight path which are natural parameters of constructing a fuel-efficient route [4].

There are two distinct classes of weather models to look at, which are deterministic and ensemble. While a deterministic model will be comprised of a single model, an ensemble model will be comprised of multiple deterministic models [5]. In an ensemble model, each of its members is initialized with slightly different values for their parameters. This will generate a forecast giving a variety of results, which provides keener insights into accurate forecast predictions. The weather data for this study comes from the Global Data Assimilation System (GDAS), which is run by NOAA. The GDAS takes in all available global satellite, conventional (rawinsonde, aircraft, surface), and radar observations to report weather conditions across the globe every six hours. This report details conditions for every latitude and longitude coordinate across 31 different pressure layers. The system is responsible for providing the initial conditions for the deterministic and ensemble weather forecast produced by the global forecast system (GFS). Currently operations within AMC still rely on the deterministic forecast while NOAA has switched to utilizing results from the ensemble forecast.

Temperatures and wind speeds are known to follow a nonlinear behavior when modeled over time. Their discontinuous and stochastic nature makes it difficult to provide accurate predictions utilizing linear approximation techniques. Artificial neural networks (ANN) can learn the underlying structure of datasets and provide accurate predictions for seemingly complex weather problems [16]. This ability has generated a huge research surge in investigating the application of ANNs to varying different weather related problems [].

The following section will discuss background literature relating to the methodologies being deployed within this work, including the difference in weather model types, ANNs, and shortest path problems (SPP).

1.3 Problem Statement

II. Literature Review

2.1 Overview

This section examines existing studies that pertain to Air Force retention, the factors that affect an individual's decision to leave the military, and the statistical methods and metrics for analyzing retention. An initial review of these studies reveals preexisting coverage of this topic and the techniques used to evaluate this issue. This should allow thorough analysis based upon the successes or failures of previous research. The literature review examines two important topics, mainly involving the specific AFSC attrition and the use of analyis on each of these AFSCs. The specific AFSC will focus on the historic and current trends of the retention rates and emerging threats to retention. The second focuses on the factors that have been effective in predicting retention and the techniques used to evaluate these factors.

2.2 Weather Models

Ensemble modeling for weather is the current method employed by large organizations, such as the National Oceanic and Atmospheric Administration (NOAA). It has been shown to be better at forecasting than deterministic models in a myriad of applications [6]. For example, Keith and Leyton displayed how weather models were better predictors of adverse where conditions, which would require aircrafts to consume more fuel than originally expected [7]. Ensemble forecasting is not always superior in every instance though. An incident in Venice showcased this, where the accuracy for predicting flooding due to storms more than four days out with a deterministic model was comparable to the ensemble model [8]. In another instance, Leonardo and Colle found that a deterministic model gave the lowest total track error when predicting North Atlantic tropical cyclones, even when compared against several different ensemble models [9]. In general, though, it is noted by the World Meteorological Organization that ensemble forecast produce more reliable results than deterministic forecast, especially when the forecast is for more than 1-3 days out [10].

2.3 Weather Factors

While some of the factors in this study may be self-explanatory, others require further detailing. Within the GDAS, wind speeds are expressed in terms of their orthogonal velocity components, which is the zonal velocity (u) and meridional velocity (v). If relating to an x-y Cartesian coordinate system, u runs parallel to the x-axis and v runs parallel to the y-axis. Therefore positive u values represent winds blowing east while positive v values represent winds blowing north. These components are then combined using the Pythagorean Theorem to acquire the magnitude of the wind. With the magnitude calculated, it is a simple trigonometric expression to discover the direction, or angle, of the resulting wind vector.

Weather measurements are recorded in the GDAS by latitude, longitude, and atmospheric pressure. Earth's atmosphere can be divided up into multiple layers which are measured for similarity around the globe by their pressure levels as opposed to actual altitude. For example, the upper edge of the troposphere may be 13 km in altitude above England, but may be 12 km high above China. Both though will have similar pressure levels, typically around 5 kPa. Geopotential height is then used to approximate the actual height of a pressure layer above the mean sea level, at the specified coordinate. Geopotential height is measured in geopotential meters (gpm), and can be thought of as an adjustment to geometric height that accounts for the variation of gravity with latitude and altitude.

2.4 Artificial Neural Networks

An ANN is a set of algorithms designed to recognize patterns, modeled loosely after the human brain. They use a form of machine perception to interpret sensory data, and label or cluster raw input. The patterns recognized are numerical and contained in vectors, in which all real-world data is translated [11]. This technique has been shown to have a high degree of accuracy when predicting weather forecasts, especially when modeling temperature, and wind speed [12].

2.5 Shortest Path Problem

In examining the mission planning problem, a network for potential flight routes can be created and treated as a SPP. This technique solves the problem of finding the path between two nodes such that the sum of its weights is minimized [13]. Recent studies looked at using stochastic SPP with correlated arcs for finding the optimal path through a future instance of the network [14]. Others have explored time-optimal paths for the solution of aircraft routing [15].

Appendix A. Relevant Theses

After speaking with my advisor, we could not find any previous theses that were relevant to my thesis.

Advisor: Raymond R. Hill

Bibliography