AIRCRAFT SEQUENCING PROBLEM SOLVE BY USING SIMULATED ANNEALING METHOD

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To my beloved father, mother and wife

Mohd Shukor bin Sharif

Che Aminah binti Awang Kechil

Camalia Saini binti Hamsa

To my supervisor,

Dr. Zaitul Marlizawati Zainuddin

Also to all my friends.

Thank you for your love, support and guidance

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ABSTRACT

Since commercial aircraft exists in the late 1960's and early 1970's, air traffic has experience a tremendous amount of growth and is now known as one of the complex logistical system. Over the past few decades, aircraft sequencing problem (ASP) has become one of the most important area of research in the OR field as the number of passengers using the air transportation has increased significantly. ASP aims is to assign each aircraft with scheduled landing time while maintaining the operational and safety constraints. In Malaysia, there is a system called Air Traffic Management (AMAN) that can produce a sequence for the aircraft to land. However, one of the weaknesses of the system is the inability of the system to provide the best route for the aircraft to land even if there is no other aircraft flying at the same period. To tackle this problem, this research will develop a program that can provide the best route for the aircraft to land by considering alternative admissible routes provided by the ATC-KL with the objective of minimizing the total airborne time of all aircrafts while satisfying the separation time constraint between the aircraft. This research will use the Simulated Annealing method with three different neighborhood structures, initial temperatures and temperature reduction formulas. From the computational results, this research has concluded that the best neighborhood structure is Swap and Reroute with an initial temperature of 300 000 and temperature reduction of $Temperature_i = Temperature_{i-1} \times P$ where P is the random number generated by the program.

ABSTRAK

Semenjak penerbangan komersial wujud pada penghujung tahun 1960-an dan 1970-an, trafik udara mula mengalami perkembangan yang pesat dan menjadi salah satu sistem logistik yang kompleks. Sejak sedekad yang lalu, Masalah Penjadualan Pesawat (MPP) mula menjadi salah satu topik yang penting di dalam bidang Operasi Penyelidikan disebabkan bilangan penumpang yang menggunakan pengangkutan udara meningkat. Tujuan MPP adalah untuk menentukan jadual pendaratan setiap pesawat di samping mementingkan faktor operasi dan keselamatan. Di Malaysia, terdapat satu sistem yang dinamakan Air Traffic Management (AMAN) yang boleh menyediakan jadual untuk pendaratan pesawat. Namun begitu, salah satu kelemahan sistem ini adalah ia tidak mampu memberikan jalan yang terbaik untuk kapal terbang mendarat dengan cepat biarpun tiada kapala terbang lain yang terbang pada masa yang sama.Untuk menangani masalah ini, kajian ini telah mecipta satu program yang mampu menyediakan turutan untuk kapal terbang mendarat dengan menggunakan jalan-jalan yang telah diberikan oleh ATC-KL dan objektif kajian ialah memngurangkan masa kapal terbang berlegar di udara sementara memenuhi syarat masa pemisahan antara pesawat. Kajian ini telah menggunakan *Simulated Annealing* dengan tiga perbezaan struktur, suhu permulaan dan formula pengurangan suhu. Daripada keputusan computer, kajian ini telah merumuskan bahawa struktur yang terbaik ialah *Swap and Reroute* dengan suhu 300 000 dan formula pengurangan suhu $Temperature_i = Temperature_{i-1} \times P$ di mana P ialah nombor rawak yang dihasilkan oleh program.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF ABBREVIATION

ALP	Aircraft Landing Problem
ALS	Aircraft Landing Sequence
AMAN	Air Manager
ASS	Aircraft Sequencing and Scheduling
ATC-KL	Air Traffic Controller Kuala Lumpur
DCA	Department of Civil Aviation
ELT	earliest landing time
FAA	Federal Aviation Administration
FCFS	First Come First Serve
IATA	International Air Transport Association
ICAO	International Civil Aviation Organization
KLIA	Kuala Lumpur International Airport
KLIA	Kuala Lumpur International Airport
LLT	Latest Landing Time
NP	Non Polynomial
OR	Operational Research
PLT	Predicted Landing Time
PLT	predicted landing time
R	Reroute
S	Swap
SA	Simulated Annealing
SR	Swap & Reroute
TLT	target landing time
TMA	Terminal Area
TMA	terminal area
TT	Total Time

LIST OF APPENDICES

CHAPTER 1

INTRODUCTION

1.1 Introduction

Since commercial aircraft become available in the late 1960's and early 1970's, air traffic has experienced a tremendous amount of growth and is now known as one of complex logistical systems. Brentnall [1] mentioned that in 2008, airlines had transported over 2.2 billion passengers and transported approximately 40% of world trade. International Air Transport Association (IATA) has reported that in 2012, growth rate on the number of flights and traveling passengers have been different in some parts of the world. In Asia, the number of aircraft movement and traveling passengers experience an increase by 6.5% and 8% respectively. Globally, IATA expects that there will be an increase of 31% in passenger demand by 2017.

The implication of this event will generate a few problems for the airport and airline industry. To overcome these problems, investment towards the system's infrastructure, expansion and modernization of the airport facilities is necessary. A recent study in 2013 done by the EUROCONTROL has identified that the aviation industry will have three challenges in the future.

The first challenge is the airport capacity. The report mentioned that due to the financial crisis in the world right now, the changes to the infrastructure and technology are difficult. In other word, a reduction on airports' plan to expand will limit the airport capacity to receive more passengers.

The second challenge is the network congestion. To operate a highly congested network safely, cost effectively and efficiently will be a problem and this will cause a major delay at the airports. Last but not least is the sustainability. To fulfill the environmental performance requirement, the industry needs to depend on the development of competitively priced low carbon fuels.

Due to the increased number of aircraft, it is expected that every day 700 to 1100 flights are delayed by 15 minutes or more [1]. Besides that, if the numbers of aircraft approaching the airport exceed the airport capacity, they will not be able to land at the "perfect landing time" and as a result fuel is wasted. To add to that, passengers might miss their connecting flights, the crew's working hours might need to be rescheduled and delays to the departing flights will occur. Thus, the task is to assign each aircraft an optimal landing time and runway so that that the total cost is minimized.

In order to reduce the delay time of the airborne flight, many researchers have identified the cause of the delay [2], [3]. For this reason, some policies were developed to solve the problem. As there is more traffic in the air, the limitations of the runway cause a bottleneck during the airport operation. As a result, the Federal Aviation Administration (FAA), has been using the ground-holding policy to reduce the delay cost. These policies will consider the airport capacity and flight schedule as fixed for a given time period and adjust the flow of the aircraft on a real-time basis by imposing "ground holds" on certain flight.

1.2 Motivation

Aircraft Sequencing Problem (ASP) is one of the biggest problem in the aviation industry. Even though there are a lot of research based on this problem, however the focus was on the static case. This research also focusses on the static case but in a different perspective. Other researchers are known to have been using the system that was already develop in order to obtain the target landing time of an aircraft. In contrast, this research developed its own system to obtain the target landing time but it leaves out a few of the important aspects such as the wind condition, time for an aircraft to change its heading and the turning rate of an aircraft.

The problem that this research tries to focus on is based on the current situation faced by the controller at the Air Traffic Control in Kuala Lumpur (ATC-KL). There, they already have a system that is capable of producing a sequence and this system is called Aircraft Management (AMAN). However, this system is not fully utilized by the controller in ATC since it does not provide the best route for an aircraft.

According to ATC-KL, the AMAN system only provides the sequence and to which point the aircraft fly. However, if the number of aircraft is manageable, it does not allow the aircraft to land as soon as possible. Instead it will route the aircraft to the longest route. Thus, controllers at ATC-KL only use the AMAN if the number of aircraft is more than what they can manage.

1.3 Background of The Study

ASP is a method to assign each aircraft with an optimal landing time and runway. A few assumptions will be considered in the ASP and they are:

a) There is only one runway for the landing.

b) The target landing time of each aircraft is predetermined and bound by its early and late landing time.

c) To avoid collision between aircrafts, separation time is considered for every pair of aircraft.

ASP can also be viewed as a routing and scheduling problem. As an example, if there are a number of customers to be picked up by a vehicle, there would be a time window given for each customer and travelling time for each customer. From here, runways represent the vehicle and customers are the aircraft. Another example is to assign number of jobs on a set of machines which will have the release time, latest finish and processing time for each job given. Thus each aircraft is assigned with an expected landing time, latest landing time and time window for it to land at the airport. Since ASP can be viewed as a job machine scheduling problem, one can conclude that the ASP is an NP-hard problem.

In ASP, there are two different cases that can be discussed, the static case or the dynamic case. Most of the articles describe the ASP as a static case where the calculation is used for scheduling an optimal queue for aircraft waiting to land at one or more runways. Since the calculation is done before any actual aircraft is near the airport, the constraints on computational time are weak and since the number of aircraft is fixed, it is possible to find an optimal solution[2]. However, the dynamic case is concerned with the final adjustment to the scheduling of incoming aircrafts. This means that this approach will wait until the aircraft are inside the range of the airport's control tower radar and then recalculate the order when the aircraft should land.

Most of ASP research focus from the perspective of modelling the problem as well as developing various optimization approaches. This include mathematical programming such as [3] and [4]. However, since the heuristic method is more flexible than a mathematical programming method, more studies have been boosted by the proposal of various heuristic method. Vadlamani and Hosseini[5], Zhan *et al.* [6], and Ciesielski and Scerri. [7] have proposed the simulated annealing, genetic algorithm and ant colony optimization in their research.

One of the weaknesses of these researches is that it produced the final schedule based on the system that is already developed [4], [6], [7]. This system can provide the final or predicted landing time for an aircraft and it already considers all the parameters that are needed for the aircraft to land. Some of the parameters are wind speed, the aircraft size and trajectory of the aircraft. However, in real situation, some of the controllers do not use this system consistently because the system is unable to give the shortest route for the aircraft.

As this research is based on the situation in the ATC-KL, they have provided all the necessary data and routes that they have used to instruct an aircraft to land. Based on this data and route, this research focuses on providing the best total airborne time while at the same time it satisfies all the constraints that were used in ASP research. Thus all the calculations are based on the initial position of the aircraft, timing that an aircraft would take to descend to a certain altitude and total time for it to fly from one point to another.

1.4 Problem Statement

Most of the researchers use the system that can provide the expected landing time for an aircraft. This is efficient as the system is already considering all the differing situations faced such as wind speed, aircraft trajectory and others. However, sometimes the system is not used by the controller in ATC-KL as they would prefer to use their experience to sequence the aircraft. However, they would use the system if an unexpected situation arose such as bad weather, too many aircraft needing to be sequenced or an emergency.

Currently, they are using their experience to route an aircraft to land as the system cannot provide them with the shortest or the fastest route for the aircraft. This is mainly because the system was set up to use only the route provided by the Department of Civil Aviation. Thus, based on this situation, this research will explore the best route for the aircraft while still being able to satisfy all the constraints in ASP. To solve this problem, the main objective is to find the best total airborne time within each hour from 0000 until 0700.

In order to solve the problem, this research focuses on all the routes that the controllers normally used if the number of aircraft is manageable. These routes are the most important topic in this research as it allows the understanding of the movement of the aircraft prior to landing. Furthermore, these routes can provide the expected landing time for all the aircraft.

1.5 Objective

The objectives of this research are:

1. To identify the best neighborhood structure, initial temperature and temperature reduction formula.

2. To provide the sequence for the aircraft to land.

3. To assign each aircraft with the route that can satisfy the separation time requirement between aircraft.

4. To minimize the total airborne time within each hour from 0000 until 0700.

1.6 Scope of Study

This study will focus on the offline data that was provided by the ATC-KL and use the route that was normally used by the controller. To obtain the time for the aircraft to descend and move from one point to the other, this research do not consider the wind condition, turning rate of the aircraft or aircraft's remaining fuel.

1.7 Significance of This Research

This research is expected to be a milestone for any researcher who wanted to develop a system for aircraft sequencing in the future. This research doesn't use the system that was already developed instead this research develops a program that will calculate the arrival time of each aircraft. However, more work needs to be done in order to have a system that can be used in the real situation.

Furthermore, this research also focuses on the method that can be used to obtain the best total airborne time of all aircraft. The route that is used in this research is based on the work experience of the controllers at ATC-KL. Thus, in the future this research can be used as a benchmark to develop a practical or usable system for the ATC.

1.8 Organization of the Thesis

For a better overview of this thesis flow, below is the organization of the thesis:

Chapter 1: Introduction

This chapter includes an introduction to the research discipline which is the aircraft sequencing problem. It also includes the problem background, problem statement, research objective and significance of this research.

Chapter 2: Literature Review

This chapter provides a thorough literature review of the study area. Extensive background work on the research discipline is also discussed here. The focus of the literature review is the ASP and SA.

Chapter 3: Research Methodology

This chapter represents the procedure of how the research was conducted and includes the research design and procedure.

Chapter 4: Simulated Annealing Implementation

This chapter discusses the mathematical model formulation that is used in this research. It includes all the routes that were given by the ATC-KL and pseudocode for the C programming part. It also includes a numerical example on how the methods in the research were performed.

Chapter 5: Results and Discussion

In this chapter, the result of the research are analyzed. The results are shown in three different sections. Then, a thorough discussion on the obtained results are put forward.

Chapter 6: Conclusion and Recommendation

In this final chapter, a quick summary of the entire research is done before concluding with the findings. In addition, a few recommendations are also forwarded for future researchers

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