AN APPLICATION OF SIMULATION APPROACH FOR ESTIMATING SUSTAINABLE RUNWAY CAPACITY

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ABSTRAK

Menilai kapasiti landasan adalah penting untuk perancangan konfigurasi landasan, jadual penerbangan dan aliran trafik berkesan. Walaupun pelbagai faktor memberi kesan kepada kapasiti landasan, kajian terdahulu tidak memodelkannya secara kuantitatif menggunakan simulasi. Kajian ini membina model Simulasi Peristiwa Diskret (DES) untuk mengukur prestasi landasan dan menganalisis pengembangan kapasitinya. Model ini diuji di Lapangan Terbang Pulau Pinang yang mempunyai satu landasan. Menggunakan model DES, tiga senario telah dipertimbangkan: meningkatkan kadar masa antara ketibaan sebanyak 20%, mengurangkannya sebanyak 20%, dan menetapkan purata kadar masa antara ketibaan sebanyak 10 minit. Kesan senario tersebut terhadap purata masa menunggu dan jumlah bilangan pesawat melengkapkan kitaran (mendarat dan berlepas) kemudiannya dianalisa. Keputusan menunjukkan senario kedua menghasilkan prestasi terbaik dari segi purata masa menunggu dan masa kitaran. Kajian ini memberikan pandangan untuk operator landasan untuk mengoptimumkan pengurusan aliran trafik udara dan menambaik kapasiti landasan.

Kata Kunci: Kapasiti landasan, landasan tunggal, simulasi peristiwa diskret (DES), prestasi landasan

ABSTRACT

Assessing runway capacity is essential for the effective planning of runway configurations, flight schedules, and traffic flows. Although various factors impact runway capacity, previous research has not quantitatively modeled the factors using simulation. This study develops a Discrete Event Simulation (DES) model to measure runway performance and analyze its future capacity expansion. The model was tested at Penang Airport with a single runway. Using the DES model, three scenarios were considered: increasing the interarrival rate by 20%, decreasing it by 20%, and setting a mean of interarrival rate by 10 minutes. The impact of the scenarios on the average waiting time and the total number of aircraft completing the cycle (landing and take-off) were then analyzed. The result showed that the second scenario produced the best performance in terms of the average waiting time and the cycle time. The research provides insight for runway operators to optimize air traffic flow management and enhance runway capacity.

Keywords: Runway capacity, single runway, discrete event simulation (DES), runway performance

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LIST OF ABBREVIATIONS

DES	**-**	Discrete Event Simulation
PEN	**-**	Penang
AAR	**-**	Airport Arrival Rate
ADR	**-**	Airport Departure Rate
ATC	**-**	Air Traffic Control
ROT	**-**	Rate of Turn

CHAPTER ONE
INTRODUCTION

1.0 Overview

This chapter start with the study background and further descriptions of airport capacity based on one of the international airports in the Northern part of Malaysia. Then, followed by the problem statement, research scope, research questions, research objectives, and significance of the study. Lastly, the end of this chapter explained the thesis organisation of this study.

1.1 Background of the study

Transportation is referred to the movements of people and things from one place to another using a variety of vehicles across different infrastructure systems (Christiansen, 2020). A thousand years have passed since the invention of transportation and the transition of transportation over the years is a truth that cannot be ignored or misrepresented (Mammadov, 2012). Every detail in the invention or manufacture of the early modes of movement has a significant impact on the movement of today (Zhao, Ke, Zuo, Xiong & Wu, 2020). According to Antolini (2022), transportation not only affected technology, but also people's time and effort, producing in not only the expected outputs of passengers traveling and freight shipments, but also adverse effects such as air pollution, noise, congestion, crashes, injuries, and fatalities. For example, Hong Kong is the one of countries listed as a country's a high level of development that is frequently facilitated by robust transportation infrastructure and well-connected transportation networks (McClure, 2017).

Basically, there are three different types of modes of transportation which are land, water, and air, and also each mode was equipped with a variety of different types of capabilities. This study focused on air transportation that relies on people and vehicles. People in air transportation systems include pilots, maintenance personnel, airport employees, and air vehicle designers, and while the vehicles used are known as aircraft. An aircraft is any vehicle that transports people or cargo through the air, and it overcomes gravity using the static lift, the dynamic lift generated by an air foil, or, in a few instances, the downward force generated by jet engines (Zhang et al., 2021).

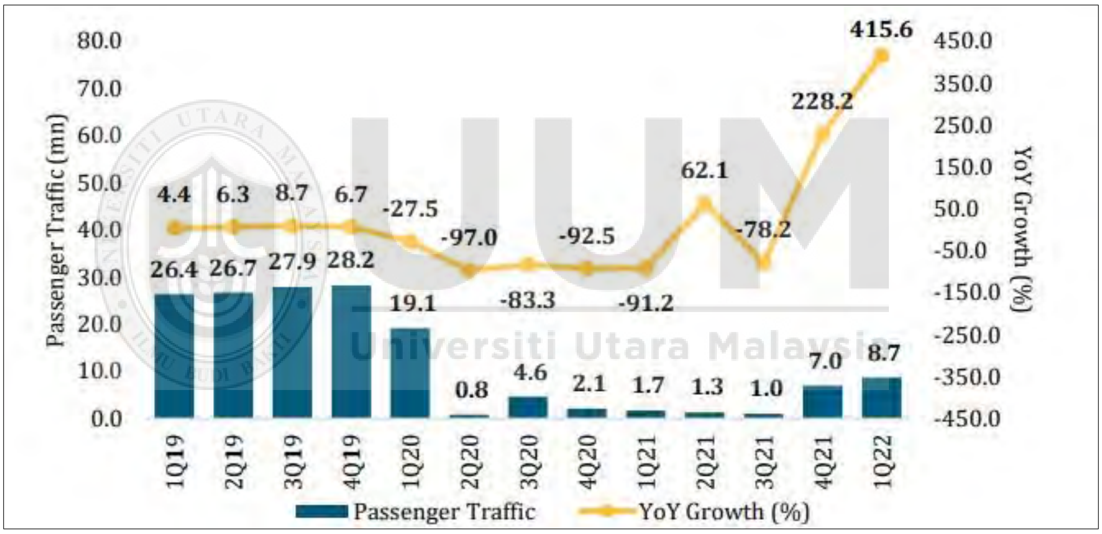

Figure 1.1: Air Traffic Passenger Demand in Malaysia (MAVCOM)

Based on figure 1.1 from Malaysian Aviation Commission (MAVCOM) stated the demand for passenger traffic in Malaysia experienced significant fluctuations between 2019 and 2022, primarily influenced by the global COVID-19 pandemic. The following analysis examines the trends in passenger traffic and year-over-year (YoY) growth during this period, highlighting the impacts of the pandemic and the subsequent recovery. In 2019, Malaysia's passenger traffic was characterized by steady demand and moderate growth. The data shows that passenger numbers ranged from approximately 26.4 million to 28.2 million per quarter, indicating a robust and stable air travel sector. The YoY growth percentages during this period were positive but modest, ranging from 4.4% to 8.7%. These figures reflect a healthy and growing demand for air travel, driven by factors such as a strong economy, increasing tourism, and a growing middle class with greater disposable income. The stable growth in 2019 set a solid foundation for what appeared to be a promising future for the aviation industry in Malaysia.

The onset of the COVID-19 pandemic in early 2020 brought about an unprecedented disruption in global air travel, and Malaysia was no exception. The data from 1Q20 to 1Q21 illustrates a sharp and sustained decline in passenger traffic. In 1Q20, passenger numbers dropped to 19.1 million, down from the previous quarter's 28.2 million. This marked the beginning of a severe downturn, with passenger traffic plummeting to as low as 1.0 million by 1Q21. The YoY growth rates during this period turned deeply negative, with the most significant declines occurring in 2Q20 (-97.0%) and 4Q20 (-92.5%).

These figures reflect the widespread travel restrictions, lockdowns, and border closures implemented to curb the spread of the virus. The aviation industry was one of the hardest-hit sectors, with airlines and airports experiencing massive revenue losses due to the drastic reduction in passenger numbers. The negative growth rates underscore the severity of the impact, as the demand for air travel virtually collapsed during the peak of the pandemic.

As the pandemic situation gradually improved and vaccination campaigns gained momentum, the demand for passenger traffic in Malaysia began to recover. Starting in 2Q21, there was a noticeable increase in passenger numbers, albeit from a very low base. Passenger traffic rose from 1.3 million in 2Q21 to 8.7 million by 1Q22. The YoY growth rates during this recovery phase were exceptionally high, particularly in 4Q21 (415.6%) and 1Q22 (228.2%).

These high growth rates, while impressive, are largely reflective of the comparison against the extremely low traffic levels of the previous year. Nonetheless, they indicate a strong rebound in demand as travel restrictions were eased, and people began to travel again for both business and leisure purposes. Government of Malaysia announced the reopening of Malaysia's international borders on 1st April 2022 is expected to recover of international travel and also increases the demand of air traffic passenger. Since Penang Airport is the third busiest airport in Malaysia which official stated by the International Air Transport Association (IATA) code of PEN, it included the one of major airport that contributed demand of air traffic passenger since Penang airport serving both domestic and international flights.

Penang has not lost in popularity with tourists, who over the years have come to adore the "Pearl of the Orient" and many returns as often as tourists can. Malaysian people are friendly and charming and Penang, with its wonderful stalls selling delicious street food, the beautiful architecture and fascinating culture is attracting a large number of tourists every year. Penang (PEN) Airport serves mainly the north of western Malaysia and the premises are medium-sized, with check-in and baggage reclaim being comparatively faster than at large sites. Penang International is mainly used by two budget airlines, namely AirAsia and Firefly. Better known carriers operating from Penang International Airport are Cathay Pacific, China Southern Airlines, Malaysia Airlines, Wings Air and Thai Airways International to name but a few. The carriers fly to destinations like Medan, Singapore, Kuala Lumpur, Bangkok, Hong Kong, Jakarta or Guangzhou.

According to Zhao et al. (2020), the top-cited article for air transportation is less time travel by using aircraft and shows people tend to use air transport rather than land transport if they need to travel long distances, so the demand for air travel had be increased. With the increased demand for air travel, the air traffic volume tends to rise (Cetek & Cetek, 2014). Despite numerous obstacles, passenger air travel was expected to grow at a favorable rate globally in 2020 (Statista, 2021). The demand for air traffic passengers decreases due to the suspension of a plan for nearly two years, from 2019 to 2021. In early 2019, the worldwide outbreak of the COVID-19 pandemic was about two years which put everyone's plan to travel on hold. Since the vaccines for the new virus were founded in 2021, the demand for air transport has increased (Santos et al., 2021). Refer Figure 1.2, the comparison between pre-covid and pos covid shows a value from negative 65.9 percent and increases to 18%. This strong demand raises severe issues about the expansion of airport capacity.

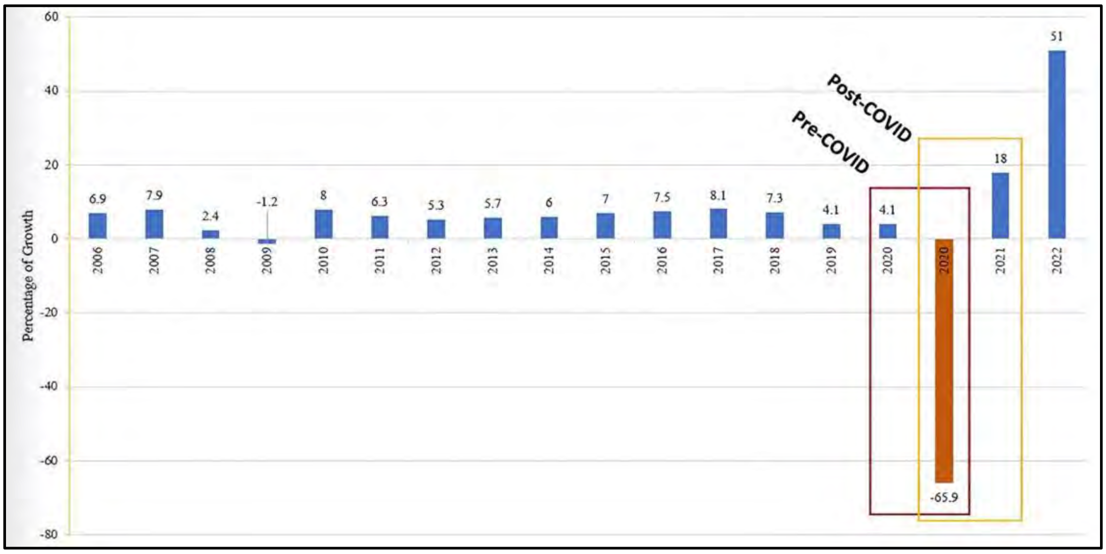

Figure 1.2: Global Air Traffic Passenger Demand Expands Annually (Statista, 2021)

Airport capacity can be defined as the estimated number of runway movements per unit time, which is typically per hour when demand is continuous (Dray, 2020). Airport capacity influences operating efficiency more than other factors: airport and regional characteristics (Qian et al., 2022). The maximum number of operations are arrivals and departures that may be completed at a specific airport at a given time interval, given certain conditions such as runway configuration, according to one definition of airport capacity (Irvine et al., 2015). The primary constraint in this study is runway capacity. Although this study has limited resources, the runway model simulation was created to analyze airport capacity performance. The critical reason for this capacity gap is that airport expansion projects are highly capital-intensive and are likely among the most significant infrastructure projects currently underway (Bazargan et al., 2002). Federal Aviation Administration (FAA) has identified a shortage of airport capacity as one of the most important limitations of commercial and private aircraft. There is a crisis for global airport capacity facing demand to expand capacity at the airport.

The expansion of airport capacity needs to consider a few essential factors to build an airport, including flight safety regulations, airspace limitations, and geographical environment. The International Civil Aviation Organisation (ICAO) established minimum safe separation distances between aircraft that must be maintained throughout the flight, take-off, and landing. For instance, after a flight has taken off, the following aircraft may not take off for between 90 seconds and two minutes. For geographical environment factor, influences the frequency of flight movement, limiting the flexibility of the operational procedures of aircraft.

According to the Airport Cooperative Research Program (ACRP), any delays in operations caused by the current traffic demand influence the value of sustainable airport capacity. Therefore, the capacity analysis may be carried out by analyzing the impact of these factors on economic, logistic, and safety concerns (Graham & Guyer, 1999). However, sustaining airport operations depends on operational planning and personnel sustainability. Operational planning refers to the techniques used by the airport's management and policymakers to efficiently and effectively manage their available resources to meet the demands of delivering the best service possible to their consumers while staying within a limited budget. Meanwhile, personnel sustainability refers to ideas for how individual airport resources may efficiently manage their everyday activities to increase service outputs and handle future problems on airport capacity.

A broad range of airport capacity models has been produced throughout the years (Di Mascio et al., 2020). This model is separated into two categories: analytical and simulation-based models. Analytical models use mathematical representations of airport operations to produce capacity estimations by manipulating these expressions. This simulation study examines several runway configurations to determine the utilisation of each airport plan's runway system. On the other hand, simulation-based models are developed as virtual components of airport operations and replicate the flow. Simulating airside ground operations, particularly on the capacity usage of available runways and the impact of its configuration, especially during peak hours, is the main focus of the study. As a result, simulation models provide reasonable estimations of airport capacity based on observations of flows in specific areas. Still, the simulation-based models allow a far higher degree of detailing, simulating airport operations at the cost and taking a much longer processing time. Thus, this study applies Discrete Event Simulation (DES) to determine the runway capacity's relative influence on the airport by using Arena software to model the design of the airport runway to sustain the airport capacity.

1.2 Problem Statements

The population rate in the world grows day by day, which means the number of passengers using public transport increases. Therefore, the government needs to find alternatives to build a new airport to sustain passengers' needs capacity by following the Federal Aviation Administration (FAA) guidelines. Furthermore, identifying suitable modeling approaches aims to understand the airport system better and properly monitor its performance and efficiency; thus, it is essential to optimize every aspect of the strategies of an airport system.

Penang International Airport in the tiny island that served 7.8 million passengers in 2018 which is four times more than Penangnites population of 1.76 million and it shown the airport was already operating at maximum passenger capacity, prior to the pandemic. According to the Edge Financial Daily, Malaysia Airports Holdings Berhad (MAHB), the federal government were unable to extend the airport because it may cost as much as RM700 million and also the expansion on PEN airport required a lot of tasks that the sources used same as built the new airport. Nevertheless, airports are public utilities, thus the government must ensure that consumers are not exploited by excessively costly investments.

Specifically, airport service and transportation systems use qualitative and quantitative methods to affect construction projects (Shoar & Payan, 2021). For this study, qualitative approaches visualise how various factors interact and quickly help the airport stakeholders understand the problems. Meanwhile, the quantitative approaches help in mathematical models that produce objective data that can be presented through numbers and statistics to evaluate the computing design and assist the stakeholder in making decisions. Quantitative model results are usually related to system performance and efficiency.

The performance of a system, including airports, can be measured using Discrete Event Simulation (DES) (Mawson & Hughes, 2019; Banks et al., 2010; Smith et al., 2015). DES has long been used as an effective tool for studying and improving the operation of dynamic systems consisting of uncertain requirements and service times, and complex interactions between different processes. Examples of domains that use the DES technique are service systems (banks, supermarkets, cafeterias, etc.), social service systems (healthcare, etc.), telecommunications systems (data packets, call centers, computer networks, etc.), and transportation systems (traffic lights). Etc.) are included. , Airports and ports) and industrial facilities (production and assembly lines). Improvements typically relate to the configuration of the input system (for example, planning the availability of available resources and their capacity) and the system structure (for example, the layout and equipment design of runways and equipment).

Whether an airport runway layout or construction is in the planning process or completed, its performance should be evaluated. Runway construction is crucial to understanding how passenger and cargo demand has influenced its performance. Furthermore, various factors affecting runway operations performance, such as traffic mix and aircraft probabilities, minimum separation time or distances for arriving and departing aircraft, runway occupancy time, and ground operating policies, are generally ignored in simulation model development. The simulation models are not adequately created and developed if these aspects are not included. As a result, the maximum possible utilisation of the runways, particularly during peak hours, and how plans may influence the runways cannot be accurately determined. Identifying runway capacity, particularly its maximum potential use during peak hours, is essential for the new airport. The Penang (PEN) runway operations decided the maximum number of passenger and cargo planes that may arrive and depart during peak hours.

1.3 Research Scope

Airport capacity consists of a few parts: runway, taxiway, and terminal capacity. Still, this study only focuses on runway capacity to choose the best runway type to build a new airport to maximise capacity usage. The most important role in aircraft to ensure the safety of aviation which are Civil Aviation Authority (CAA) and the International Civil Aviation Organisation (ICAO) state that, runway safety is essential when running an aircraft. The area of interest covers only landside operations, which is runway design. The interest is from January to March 2021 and continued in November 2021. The reason data continued collecting in November was the phase when the economy continued operating. This study went on going when the pandemic happened, and it disrupted the travel sector when countries closed their border. All types of aircraft were treated as moving entities throughout the system and this model is tracing a single entity. The modeling of PEN Airport was designed in Arena software using the Discrete Event Simulation (DES) method. This location covered in the study is Penang (PEN) Airport because the model replicated to calculate the performance of runway capacity for a single type of runway.

1.4 Research Questions

A research question is relevant to the problem statement and may be directly answered through data analysis. Therefore, several research questions have been prepared for this study, as follows:

1. How to simulate airport configurations such as runways based on PEN runway airport data using computer modeling?

2. What is the maximum potential usage of the PEN runways airports during peak hours?

3. How to evaluate the different scenarios of potential improvement at PEN runway airport?

4. How is the runway capacity of the PEN airport affected by future or operating policies?

1.5 Research Objectives

The main objective of this study is to develop a Discrete Event Simulation model on runway capacity of airports based on PEN International Airport data, using Arena software. To fulfil the main objective, three sub-objectives must be completed. The following are the study's sub-objectives:

1. To evaluate the performances of PEN runway capacity during peak hours.

2. To construct the what-if-analysis for several scenarios of PEN runway capacity.

3. To provide some alternatives for best scenario in order to improve runway airport development plans of the operating policies.

1.6 Significance of Study

This study provided recommendations and new insight toward people among air transport organisations into runway airport capacity performance. This case study is based on PEN International Airport data that used only a single runway for aircraft landing and take-off to maximize capacity usage.

Through this study, many stakeholders should profit from the suggested solutions. The outcomes are believed to provide the guidelines and, perhaps, give awareness to the respective parties responsible for handling.

1.7 Thesis Organisations

This thesis is structured into five main chapters. Chapter 1 introduces the study by outlining the background, problem statements, research scope, questions, objectives, and significance, concluding with the thesis organisation. Chapter 2 provides a literature review, covering air transportation services, airport configurations, and runway capacity, focusing on Penang Airport. Chapter 3 details the research methodology, including the research framework, model development, and the use of Arena software for simulation. Chapter 4 presents the output analysis and findings, comparing the basic model with different scenarios and discussing the results. Finally, Chapter 5 concludes the thesis by summarizing the findings, discussing the study's contributions, identifying limitations, and offering recommendations for future work.

CHAPTER TWO
LITERATURE REVIEW

2.0 Overview

This chapter provides an overview of previous research on knowledge sharing and interests. It introduces the framework for the case study that comprises the main focus of the research described in this thesis. A variety of solutions have been used as approaches to overcome this challenge, indicating that there is great interest in the area. This chapter also goes through the various methods in detail. The best strategy regarded to be the most suitable way to solve the airport capacity problem in the context of the current study is addressed at the end of the chapter.

2.1 Transportation

Transfer or transit is the movement of people, animals, and goods from one place to another. In other words, the transport process is defined as a specific change in the organism or the situation from one point to this endpoint. Means of transport are wind, land (rail and road), water, cables, pipes, and space. This environment can be divided into structures, vehicles, and processes. Transportation is important because it enables human-to-human exchanges, which is important for growing cultures in Malaysia.

During British colonial rule, Malaysia's transportation infrastructure began to grow. As a result, the country now has a diverse and well-developed transportation system. The road network in Malaysia is extensive, with a total length of 250,023 km, of which 1,956 km are highways (as of 2019). The primary road in the country runs for 800 kilometres, and the road connects Singapore with the Thailand border. East Malaysia's road network is underdeveloped compared to Peninsular Malaysia's. Commuter trains and rapid transit are popular in cities, which reduce the traffic load on other systems and are considered safe, comfortable, and reliable. There are various ways to get throughout Peninsular Malaysia using public buses, trains, cars, motorcycles (particularly those in the states of Perlis and Kedah), and commercial flights.

Air travel is an essential factor in achieving economic growth and development. On a domestic, regional, and worldwide scale, air travel encourages integration into the global economy and offers important linkages. It contributes to the growth of trade, tourism, and employment opportunity. Thus, the pandemic that happened in 2019 seriously impacted air transport. During that, pandemic, several governments drastically decreased foreign flights, and some airlines suddenly went bankrupt (S. Li et al., 2021).

2.2 Air Transportation Services

Air transportation has about eight types of air transport which are commercial airplanes, helicopters, private planes, blimps, gliders, hang gliders, zeppelin, and parachutes. Air transport has two modes which are helicopters and airplanes. Most frequently used in travel for a short distance are helicopters due to their low speed and flying at a low altitude. Meanwhile airplanes travel at high altitudes and have higher speeds, fly long distances, and can accommodate more people to travel.

2.2.1 Status of Airport in Malaysia

Malaysia's airport has 62 in total, 38 in East Malaysia, and 24 in Peninsular Malaysia. Of the total airports, only eight are international airports. The listed international airport can be referred to in Table 2.1. Malaysia Airlines, AirAsia, and Malindo Air operate major international and domestic routes between West and East Malaysia, while more minor domestic routes are handled by smaller airlines such as MASwings, Firefly, and Berjaya Air. MASkargo and Transmile Air Services are two major freight carriers. Malaysia's economy is one of the most competitive in Asia, and it continues to grow at a rapid pace year after year. According to experts, Malaysia had a gross domestic product (GDP) of 1.002 trillion in 2018, making it the world's 26th largest economy (Lang'at, 2018). The Southeast Asian country also has a solid industrial sector, meaning that products and people flow regularly in and out of the country. As a result, numerous big international airports with considerable passenger and freight traffic have been established and still growing on-demand.

Malaysia's main and busiest airport is Kuala Lumpur International Airport. In terms of international passenger traffic, it was the twelfth busiest airport in the world in 2018, with over 43.5 million passengers (Tiwari & Kainth, 2014). Kota Kinabalu International Airport, which serves Malaysia's second-largest urban area and is the busiest in East Malaysia with over 8.6 million passengers in 2018, is another vital airport. Table 2.1 shows the rank of the busiest airport in Malaysia with the count of annual passengers in Millions and the data collected from the Statista website.

Table 2.1
List of Busiest Airport in Malaysia based on annual passenger count

Rank	Airport	Annual Passenger Count (Millions)
1	Kuala Lumpur International Airport	58.6
2	Kota Kinabalu International Airport	8.0
3	Penang International Airport	7.2
4	Kuching International Airport	5.1
5	Senai International Airport	3.1

2.2.2 Demand for Air Transportation in Malaysia

According to the Malaysian Aviation Commission (MAVCOM), air passenger traffic would increase by 316 to 525 percent year on year in 2022, to between 32.6 million and 49.0 million passengers (Dg et al., 2019). In 2019, this would represent a 30 to 45 percent recovery from pre-pandemic levels of air passenger traffic. The surge in Brent crude oil and jet fuel prices, which might affect operating expenses, as well as probable outbreaks of additional COVID-19 variants, especially the fast-spreading Omicron version, could pose substantial difficulties to the aviation sector. However, The business continued to grow, particularly as the Malaysian government explored reopening mutual border crossings with several other countries.

2.2.3 The Importance of Air Transport in Malaysia

According to International Air Transport Association (IATA), Malaysia's air transportation sector makes a major contribution to the country's economy. Airlines in Malaysia. The effect of air travel on an economy can be measured in various of ways. Jobs and spending generated by national airlines and their supply chain, trade, tourism, and investment flows resulting from users of all airlines serving the country, and city pair connections that make these flows possible are three perspectives that can be obtained in order to measure the importance of airports to the Malaysian economy (Martin, 2016). All of it offers a unique yet insightful viewpoint on the relevance of air travel.

2.3 Configurations of International Airport

An airport is a large transportation hub that serves planes, passengers, cargo, and surface vehicles. Different components of an airport serve each of these users. An airport's components are usually divided into two groups. They are as follows:

- Landside: This area includes all parts of the airport that are accessible to the general public without having to go through security screening. It typically includes areas such as check-in counters, baggage claim, ticketing desks, restaurants, and parking lots. Passengers, visitors, and airport staff can access these areas freely.

- Airside: This area refers to the secure, restricted zone of the airport, which is only accessible to passengers with boarding passes, airport staff, and authorized personnel. It includes areas like departure gates, runways, taxiways, and aircraft parking areas. To enter the airside, individuals must pass through security screening.

The airfield component of an airport consists of all facilities, such as runways, taxiways, aprons, navigational aids, and other amenities, that are placed on the airport's physical property to support aircraft operations. The landside aspects of an airport are designed and managed to allow ground-based vehicles, people, and items to move freely.

It is in addition divided into the airport terminal and airport floor get admission elements to facilitate passenger and baggage transit from the landside to plane on the airside, as well as ground-based car site visitors to the surrounding metropolitan area (Ahmed, 2014). The components of an airport are designed in such a way that correct mobility from one component to the next is possible. The figure shows an example of a typical flow of motions between components that was adapted from the Federal Aviation Administration (FAA).

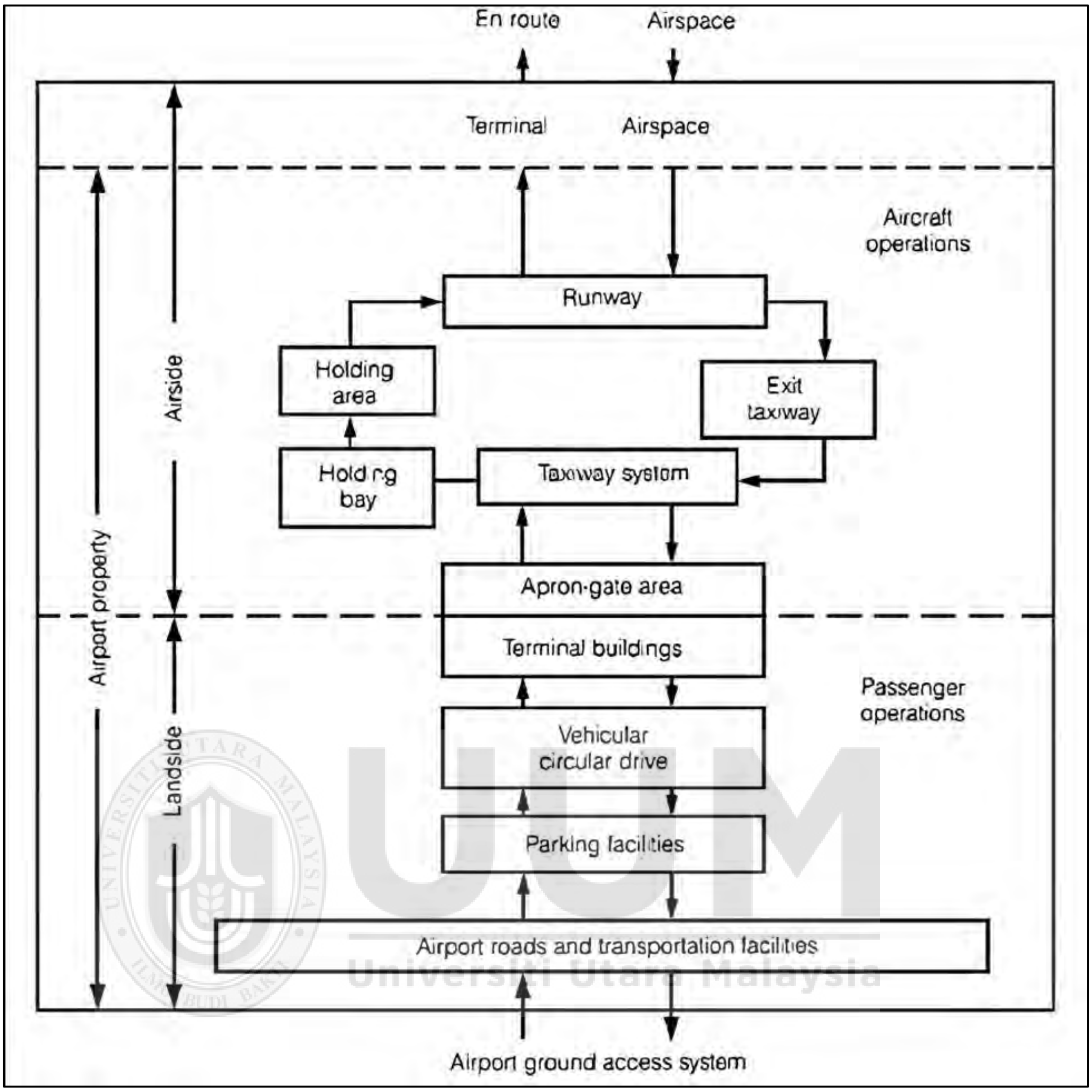

Figure 2.1: Components of an Airport

Based on Figure 2.1, this study only focuses on an airside area which is the runway of the airport.

2.3.1 Runway

The most imperative facility in the airport is the runway. The desired aircraft would be unable to operate at the airport except for a well-planned and controlled runway. As a result, when planning runways strict sketch hints ought to be followed, with specific criteria for runway length, width, orientation (direction), configuration (of a couple of runways), slope, and even pavement thickness, as well as the immediate airfield area surrounding the runways, to ensure that no dangerous obstructions are preventing the plane from flying safely. The markings, lighting, and related airfield signage that pick out runways and supply directional guidance for plane taxing, takeoff, approach, and touchdown make runway operations greater effective. The type of aircraft that uses the runway determines the runway's design and operation (Ahmed, 2014).

A runway layout is a rectangular section of an airport's surface that has been prepared for aircraft takeoff and landing (Horonjeff, 2010). The desired aircraft would be unable to use the airport without a well-planned and controlled runway (Fisher, 2012).

2.3.1.1 Runway provided at PEN Airport in Malaysia

The PEN airport only has a single runway, which is approximately 10,997 feet (3,352 m) long. The single runway means the aircraft used the same runway to depart and land at the airport. A detailed explanation of the design of PEN Airport's runway can refer in chapter four.

2.3.2 Terminal

There is a direct connection between an airport airfield and the terminal area. The intended purpose of an airport is to facilitate the movement of human beings and items with the aid of air, and the terminal area performs an essential role in reaching this goal with the aid of connecting the airport's airside and landside. The airport terminal region is included passenger and cargo terminal buildings, public transportation hubs, and planes for parking/unloading/refueling/service facilities. These hubs are critical to the airport's basic operation. There are numerous techniques in which the facilities of the passenger constructing gadget are bodily organised and in which a range of passenger processing operations are carried out. The most integral choice is whether or not processing ought to be centralised or decentralised (Horonjeff, 2010).

The centralised passenger processing means that the system of facilities is housed in one building and passengers are used processing all utilising the building. While the decentralised passenger processing is arranged in smaller modular units and that building is repeated with more buildings. Terminal design concepts are shown in Figure 2.2.

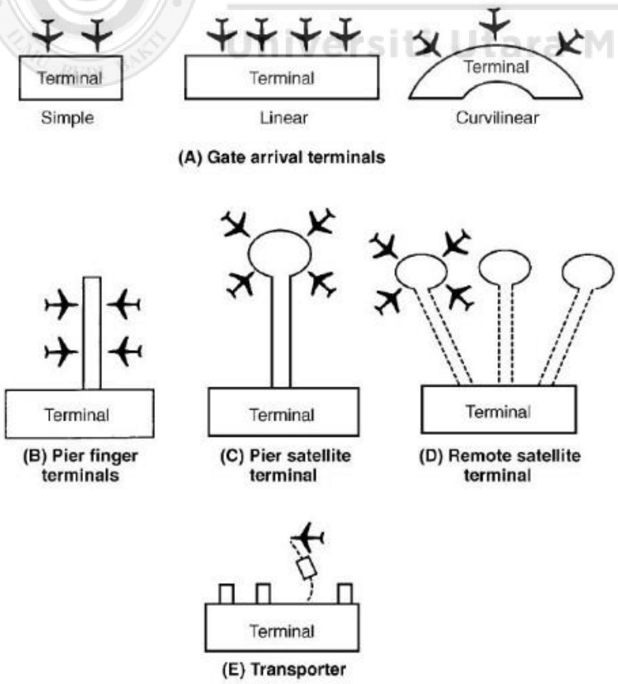

Figure 2.2: Terminal Design Concepts

Figure 2.3: Terminal PEN Airport

Figure 2.4: Close Up Terminal PEN Airport

Based on the figures above, it has been proven the diagram concept for the terminal at PEN Airport is used a linear design. The most centralised of all preparations are the easy linear arrangement, which may additionally be operated with one terminal, with passengers getting entry to the plane with the aid of a direct connection to the most terminal building. The operation was either with or without specific gate assignments to unique airlines permanently. Since this type of arrangement offered a short length of the airside interface relative to the size of the terminal, it was frequently used for low-volume airports.

2.4 Issues on Airport Runway Capacity

The first issue involving airport runway capacity is airport congestion pricing. Aviation revenues under welfare maximisation are below their costs because the optimal airport fee must be set below the first-best level to balance market power in the non-aviation market, resulting in insufficient revenues (Taleizadeh et al., 2018) (Basso & Zhang, 2006). The result of each case of exogenous and endogenous costs of another good. Once the worth of another good is exogenous, the price higher (lower) than the marginal cost within the another-good market makes cost recovery less (more) possible. If the price of another good is endogenous, cost recovery is additional likely (unlikely) to carry when non-aeronautical service and another good are nearer enhances (substitutes) or/and the airport absorbs more (less) profits from aspect business (Kidokoro & Zhang, 2018).

Next, the environmental effects of aviation continue to be a fundamental impediment to the sustainable growth of aviation. The noise pollution occurred at the airport runway system due to rising air traffic. Noise and air pollution have been identified with airport expansion in Malaysia (Sahrir et al., 2012). Also, accurately predicting noise can be based on noise-power-distance (NDP) curves but not included the effects of landing gear positions and airframe configurations (Geissbuhler et al., 2022). This researcher has chosen parallel runway operations to demonstrate noise pollution major happens on this type of runway. In addition, aircraft noise affected on psychosocial health (Faiyetole & Sivowaku, 2021). The noise of aircraft may increase the symptoms of depression through various mechanisms (L. Li et al., 2021). Noise pollution triggers stress once it exceeds a person's ability to cope, which in turn leads to depressive symptoms such as fatigue, poor concentration, or reduced happiness.

Besides that, climate change is a long-term shift in average weather patterns that have come to define the Earth's local, regional and global warming and also the issues for airport runway capacity. The situational awareness map of the airport reveals the impact on estimating flight departure delays (Shao et al., 2022). Due the bad weather also cause congestion on runway capacity and is a major cause of ground delay programs. The other issue on the airport runway is foreign object debris detection (FOD). Foreign object debris refers to any suspicious material on the airfield that causes an accident on the airport runway and threatens the aircraft and airport system. FOD can be found when used with the radar method (Y. Wang et al., 2022).

The air transport system in general is more complex than a motorway system in a very special way. While most road movements are point-to-point (motorists rarely change vehicles en route), most major airlines operate hub-and-spoke systems, where people travel through a hub and change routes. This means that airlines are not only concerned about the immediate impact of flight delays but also about the impact on connecting traffic and their additional network operations. The summarised table can refer to table 2.2 for the issue related to airport runway capacity to understand the impact on runway capacity.

Table 2.2
Issues with Airport Runway Capacity

Author(s)	Issues
Kidokoro & Zhang, 2018 Taleizadeh et al., 2018 Basso & Zhang, 2006	Airport congestion pricing
Sahrir et al., 2012 Geissbuhler et al., 2022 L. Li et al., 2021	Noise pollution, psychosocial health
Shao et al., 2022 Wang et al., 2022	Climate change, foreign object debris

2.5 Techniques Used in Measured the Performance Airport System

The impact of the runway system includes a feasibility study that looks into the effects of changing the runway system configuration on operational airside capacity performance. The current operational performance framework in the context of an airport to explain the impact or stability (resilience) of observed performance is dependent on the runway system configuration in use (Meson-Mancha et al., 2019). This researcher used a data-driven approach in order to determine the runway system configuration.

The runway system has two types of lanes which are single and multi-lane highways. Multi-lane highways are the channel of traffic used between collector roads and freeways. The capacity ranges from modest to large and is built to strike a balance between traffic mobility and accessibility (Khattak et al., 2019). This researcher has used two types of methods which are discrete event simulation (DES) framework and phase-type distribution (PHD) to develop the model of the runway and this case used random traffic flow. The parameter settings used in this study are the arrival rate of the vehicle, the squared coefficient of variation (SCV) in the arrival interval, and the number of lanes.

Jurczyk and Kutyba explored the use of Discrete Event Simulation for calculating airport runway capacity. Employing FlexSim 3D Simulation software, this researcher developed a model that incorporates various operational factors, such as runway and taxiway configurations and aircraft arrival and departure rates. While the study does not delve into the specifics of the DES techniques implemented, it concludes that DES, particularly through the utilization of FlexSim, presents a valuable tool for determining and analyzing airport runway capacity.

In a study conducted by Wang et al. (2022), the operational performance of 21 major international airports was evaluated over the period from 2016 to 2019 using various Data Envelopment Analysis (DEA) models. The research focused on assessing the efficiency of runway designs, with input factors including runway numbers and dimensions, and output factors encompassing annual flights and passenger numbers. The findings revealed that London Heathrow and Munich International airports consistently demonstrated high efficiency in runway utilization across all applied models. Notably, the study also highlighted that Asian airports with parallel runway designs exhibited higher efficiency compared to their North American and European counterparts. This research offers valuable insights for airport operation managers, decision-makers, investors, and policymakers by providing a benchmark for evaluating airport performance based on different runway configurations. Furthermore, by analyzing runway efficiency, the study contributes to a broader understanding of the factors influencing airport operational performance, which is vital for fostering economic growth, job creation, and facilitating international trade and tourism within the aviation industry (C. N. Wang et al., 2022).

Table 2.3
Techniques Used in Measured the Performance Airport System

Author(s)	**Techniques used**
Meson-Mancha et al., 2019	Data-driven approach
Khattak et al., 2019)	Discrete event simulation (DES) framework, phase-type distribution (PHD)
(Kalbarczyk et al., 2023)	Discrete event simulation (DES), FlexSim 3D Simulation
(C. N. Wang et al., 2022)	Data Envelopment Analysis (DEA)

2.6 Choosing the Suitable Techniques for Design Runway Capacity for Case in Penang Airport

The order to accurately evaluate airport capacity is essential to air traffic flow. This is because wrong capacity forecasts result in unnecessarily high costs, and unavoidable management delays (Kicinger et al., 2011). Various input factors in a discrete system may often be modified to improve output performance. For example, the arrival rates of passengers and cargo, as well as the number of available resources, are inputs for an airport system (e.g., runways, gate counters, and available personals). Meanwhile, the outputs include wait times in relevant lines, passenger and cargo cycle times, the number of passengers served, and resource usage (e.g., gate and runway busy times and bed occupancy rates). By verifying these input parameters and studying their impact on output performance metrics, various potential system configurations and structures can be identified for future improvements before implementation. Effective input management to minimise operating costs and achieve a satisfactory level of performance outputs is especially important for systems with ever-increasing demand, such as airport systems. Inefficient management of systems can lead to various negative effects (e.g. in terms of long waits in queues and increased number of passengers served outside tolerance limits) which consequently reduce the quality of their level on duty. Therefore, the effectiveness of an alternative configuration must be evaluated against other alternatives. This operational efficiency can be assessed using Discrete Event Simulation (DES) and Data Envelopment Analysis (DEA) (Thanassoulis et al., 2016) must be used.

DES is a simulation of systems whose behavior changes only at specific intervals of time. With DES's latest commercial tools, modeling such systems was never easier. Arena (Zou et al., 2014), Flexim, and SIMUL8, for example, are great tools for constructing complex DES models using drag-and-drop, embedding high-quality animation and structure visualization, and analyzing their quantitative performance using user-friendly environments and a variety of sophisticated analysis modules. These technologies should be used to create airport simulation models so that the relative efficiency of any operational choice can be easily compared to other prospective operational alternatives that airport management is considering. They are able to compare the relative efficiency of the various input setups as a result of this.

Because of the importance of runway capabilities to overall airport operations, several recent articles have focused on runway simulation. On the other hand, the simulation did not include diverse factors impacting runway capacity performance as essential inputs. As a result, developing DES models that incorporate these aspects is critical for the KXP airport's management to obtain insight into the performance of the runway operations as a result of the PEN runways. Using the DES models could take the necessary steps to enhance the airport's performance and ensure Malaysia's economic development in the future.

CHAPTER THREE
METHODOLOGY

3.0 Overview

In Chapter Three, a full explanation of each process involved in performing the DES investigation is presented in this chapter. As illustrated in section 3.1, the stages are laid out in a flowchart. All related steps in this study are explained in this chapter.

3.1 Research Framework

Work using ordered processes rather than disorganized procedures would be easier. A research framework may serve as a guide, and the entire process can be recorded to eliminate any potential detours from the goals. The flowchart of the DES framework for this investigation is shown in Figure 3.1, which is adapted from Banks, J., Carson, J., Nelson, B., & Nicol, D. (2009).

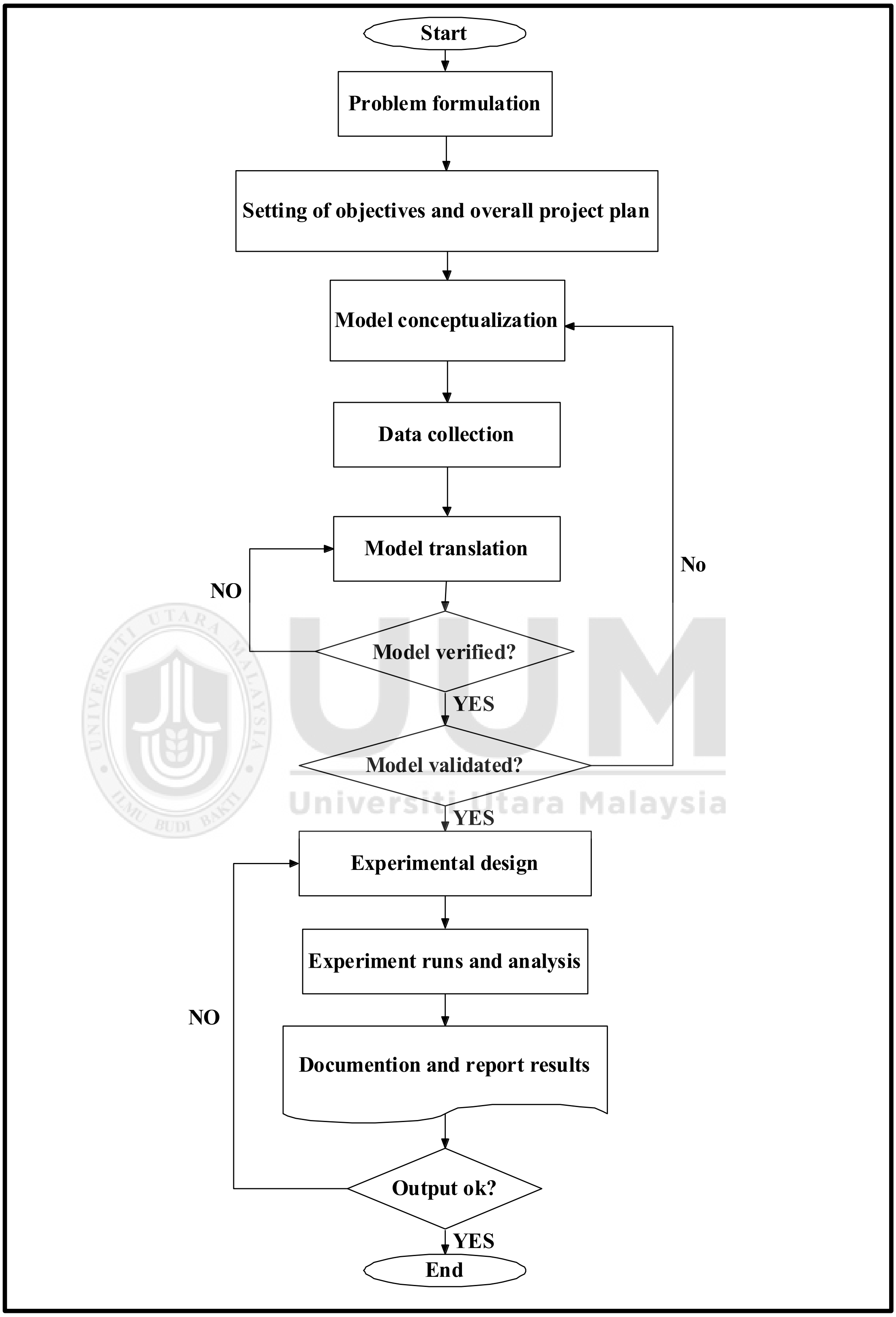

Figure 3.1: The Flowchart of DES Framework

3.1.1 Problem Formulation

The statement of the problem begins in every study. In this study, the main problem encountered was developing an expansion runway that only uses a single type of runway. In order to ensure the usability of the runway is at the maximum level or not, a study was undertaken using the Discrete Event Simulation (DES) method. Furthermore, Penang (PEN) Airport's runway in Penang is a mixed mode used for departure and arrival on the same runway. Based on Figure 3.2, the yellow arrow indicates the aircraft entering the runway for either departure or landing, while the blue arrow shows the aircraft leaving the runway and entering the airspace area. The grey bar represents the runway used by aircraft for both departures and arrivals.

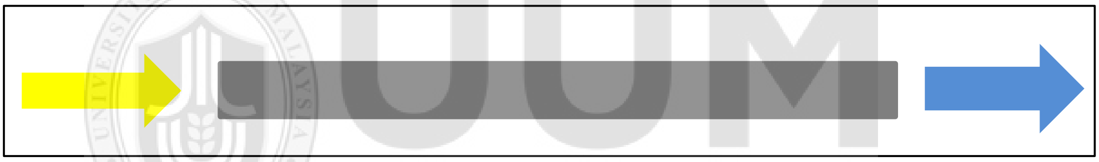

Figure 3.2: The Mixed of Modes Layout for Single Runway

3.1.2 Setting the Objectives and Overall Project Plan

The next step of the DES simulation was to define the study's objectives after the problems had been identified. The objectives were formulated to overcome the study's problems of what needed to be accomplished at the end. The main purpose of this study was to develop a Discrete Event Simulation model on the runway capacity of an airport based on Penang data using Arena software. To do so, thorough development of the runway design, the aircraft on the ground, taxiway design, the type of aircraft, and various other dynamic activities within the air transportation network were required to replicate the model. Using the Arena program, a simulation model was created to replicate the activities inside the PEN airport network.

3.1.3 Model Conceptualisation

The model conceptualisation was the next step in DES stimulation. To start developing the model, the idea of the concept must be understood. This phase consisted of brainstorming perspective module blocks for the simulation model development. In Chapter Four, the operation of PEN airport and all information about the system are further discussed.

3.1.4 Data Collection

Specific secondary data was acquired to develop a simulation model for data collection. While using previously collected data, secondary research, also known as desk research, is a form of research. Existing data was summarised and compiled to improve the overall efficacy of the research.

Secondary data is collected from various sources such as public libraries, websites, and data from previously conducted surveys can make these materials accessible among other sources. Some government and non-government organisations also maintain data that can be retrieved for research purposes. Secondary data is much more cost-effective than primary data because it utilises existing data. In contrast, primary data requires businesses or organisations to collect data themselves or hire a third party to do so.

This study used secondary data collected from the internet. The data is collected from the official Penang Website and Flight Radar to collect flight arrival and departure times. The type of data needed would be to calculate the times between arrival, the service time, and aircraft type. The categories of the aircraft such as small, medium, and large can be identified from open resources or directly referred to the flight radar official website.

3.1.5 Model Translation

After the model has been conceptualised to represent the real-system problem clearly, the next step is model translation. For this study, all the operation logic is being translated using modules in Arena software to simulate the actual activities within the air network and runway. A detailed explanation is in chapter four.

3.1.6 Model Verification and Validation

The verification raised concerns about the model's performance. It was strongly advised to be completed quickly and understand the verification phase. The use of animation as an interactive run controller aided in the work of verification. This research also included a task called tracing a single entity. The goal of this work was to ensure that the moving entity's accuracy was maintained throughout the simulation duration. Any model developed to simulate a real-world situation never be valid if no validation activity is undertaken. To put it another way, validation is a procedure that determines if the model can be used in place of the real thing.

3.1.6.1 Model Verification

Model verification in simulation refers to the process of testing and validating a model using a computer simulation. This involves running the model under different conditions and scenarios to ensure that it behaves as expected and produces accurate results (Yin & McKay, 2018).

During model verification, inputs are provided to the model and the outputs are compared to expected outcomes. This helps to identify any errors or discrepancies in the model, which can then be corrected and tested again until the model is deemed reliable and accurate. By verifying the model in simulation, potential problems can be identified and addressed before investing time and resources into building a physical prototype or implementing the system in the real world. This can save time, money, and reduce the risk of failure or unintended consequences.

For this study, in order to ensure the model developed correctly, the flow of the simulation was visually checked and the animation of the real system was constructed. Refer to Figure 3.3, based on this figure there are no any error in this model.

The animation is constructed in Figure 3.4 to replicate the reliability of the real-world condition. During the verification phase, the flow of a single entity throughout the flowcharts was traced. The flow of the entity was examined over a specific duration to ensure that it was closely aligned with the intended process.

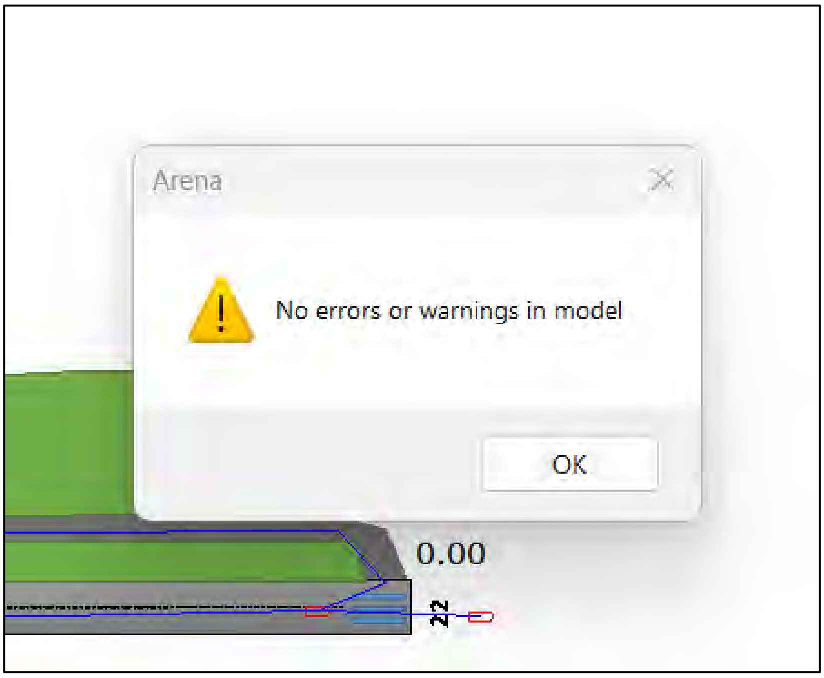

Figure 3.3: The model verification on Arena Software

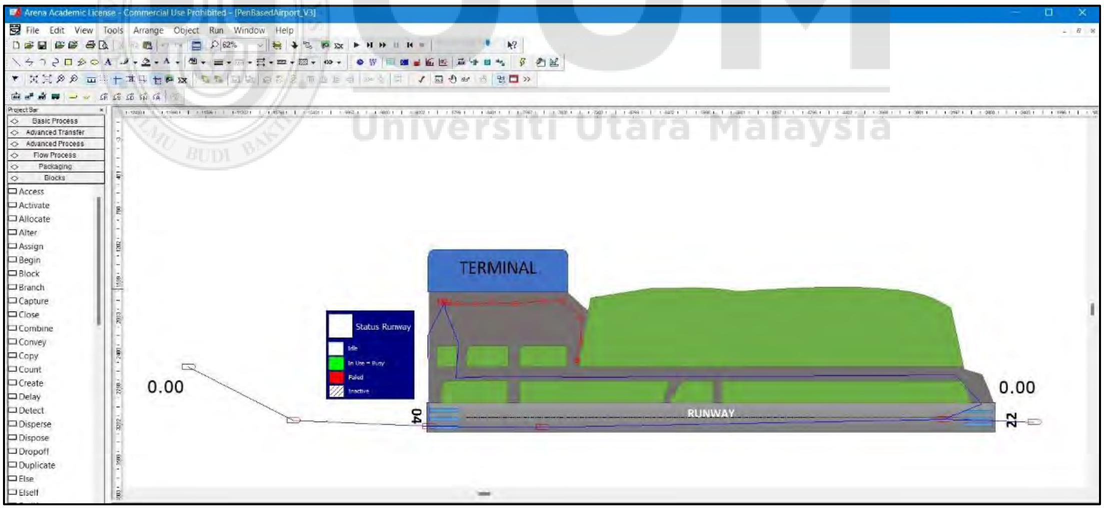

Figure 3.4: Visual Runway Presentation based on Penang Airport

3.1.6.2 Model Validation

Model validation in simulation is the process of ensuring that a simulation model accurately represents the real-world system it is intended to model. This involves comparing the output of the simulation to real-world data or observations to determine if the model accurately predicts system behavior. In other words, it's the process of checking whether the simulation model is a good representation of the actual system and whether the predictions and results of the simulation match what would be expected in the real world.

The purpose of model validation is to ensure that the simulation model can be used with confidence to make predictions about the real-world system. If the model is validated, it can be used to make predictions about the system's behavior in different scenarios or under different conditions. If the model does not accurately represent the real-world system, it may need to be revised or updated before it can be used for predictions or decision-making. To achieve this, it is necessary to calculate a validity level and ensure that the model accuracy is 10% or lower (Kim & Hansen, 2010). The validity level refers to the maximum allowed percentage for the output. Use the provided formula to calculate the validity level:

$$Validity\ Level = \frac{\left||Output(Data) - Output(Simulation)|\right|}{Output(Data)} \times 100$$

$$= \leq 10\%$$

For the airport runway study, the validity level filter for atypical circumstances to which air traffic controllers responded by raising or lowering the airport arrival rate(AAR) and airport departure rate(ADR) to unusually high and low values (Kim & Hansen, 2010). These circumstances could include nonfunctioning navigational aids, adverse terminal area weather, configuration transition periods, reduced staffing in the control tower, and others. Because these circumstances are not accounted for as independent variables in the capacity model, their impacts on capacity through this filter are eliminated. In this study, the first arrival and last arrival were recorded and the freqeuncies at Penang Airport are calculated.

Validaty level for Runway:

$$= \frac{||Output(Data) - Output(Simulation)||}{Output(Data)} \times 100$$

$$= \frac{||94-89||}{94} \times 100$$

= 5.31%

As shown value above, the validity level for the runway is lower than ten percent which indicates that the model is valid enough to be considered as accurate. The value of 89 was from the average system number out of the simulation while the value of 94 is from the average of real data collected, refer the Appendix A for more details on the data output.

Once the model has been verified and validated, the experimentation phase takes place to search for a better solution with the aim to maximize the utilization of runway capacity as discussed in the next section.

3.1.7 Experimental Design

The experimental design was the next step in the DES technique. Several scenarios were created to meet the sub-objectives, which necessitated what-if analysis. Different temporal configuration choices were evaluated based on the thought to contribute to congestion at the airport runway. Data is required to identify the characteristics of input and output runway simulation models. The relevant data collected: Traffic mix and aircraft probabilities, minimum separation time, runway occupancy time, and ground operating policies. In Chapter 4, a detailed explanation was presented.

3.1.8 Documentation and Report Result

In the last stage, all results and outputs were presented. When there was no additional improvement to get the best runway layout to maximise airport capacity utilisation, the experiment was called off.

3.2 Model Development

A detailed explanation of the model's conception was also provided, including a system description and a runway operation. This chapter also investigated the input data in modeling, model translation, and model assumptions.

3.2.1 Model Description

The system involving the related elements is discussed in the model description section.

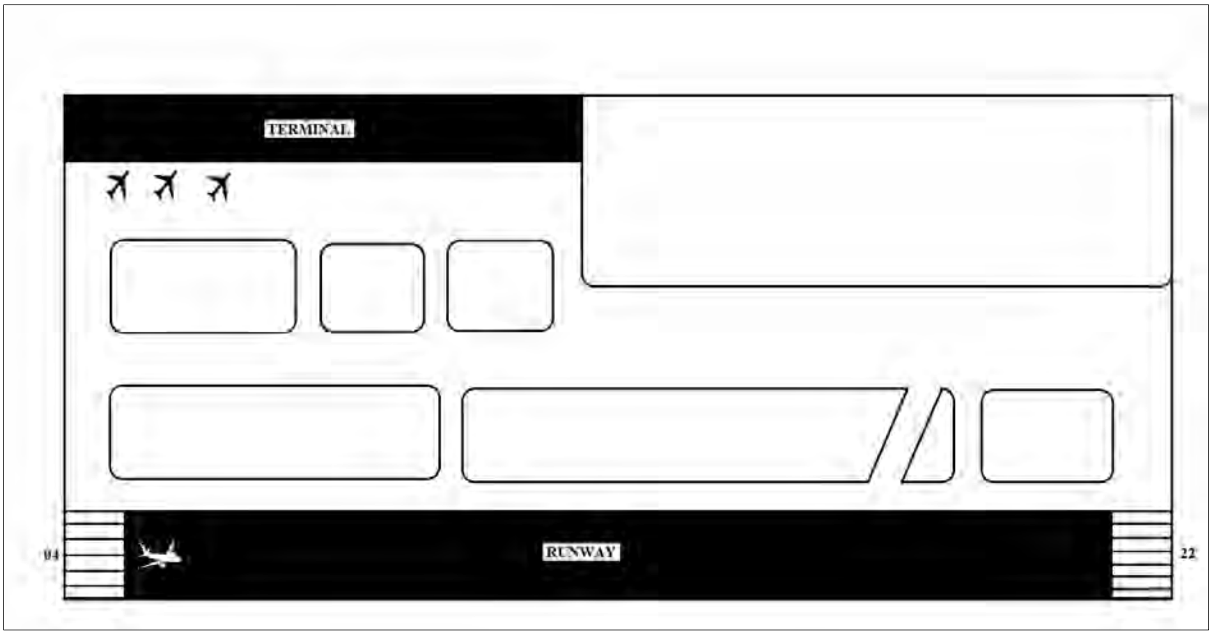

Figure 3.3: The layout of Penang airport's runway

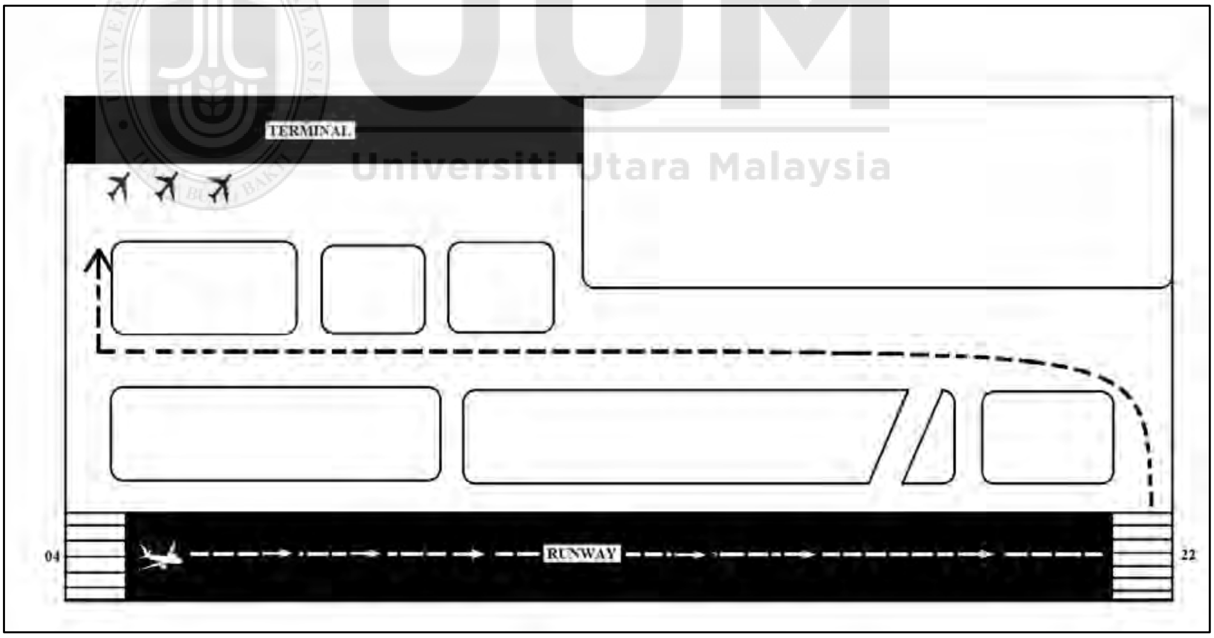

Figure 3.4: Detailed layout of aircraft movement for arrival

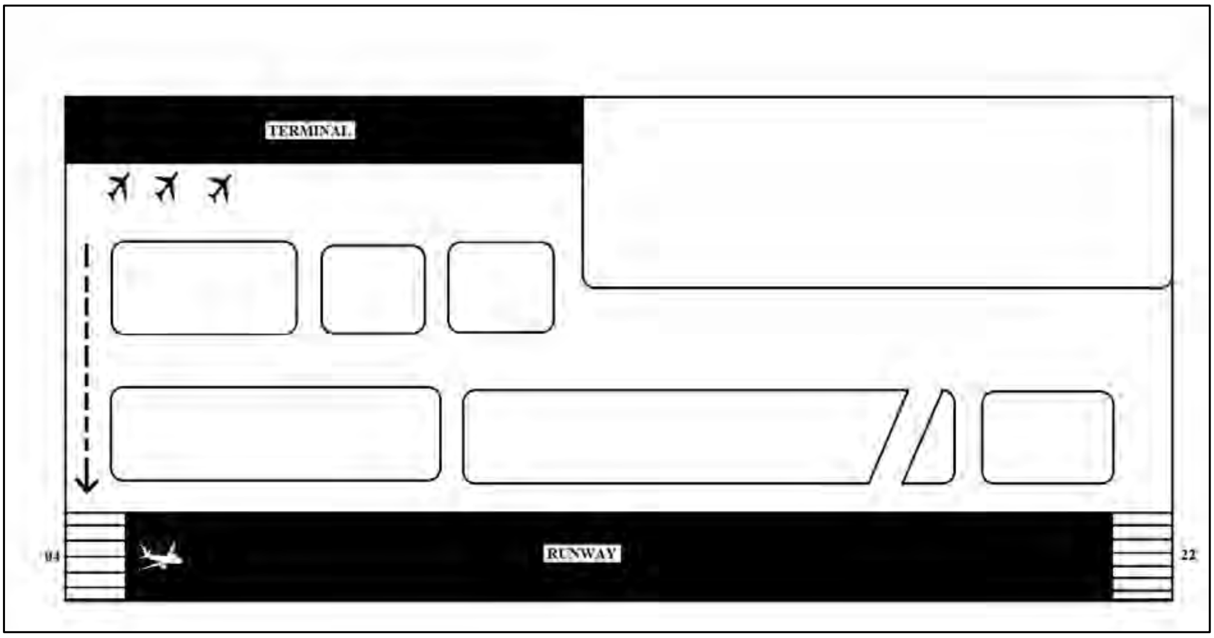

Figure 3.5: Detailed layout of aircraft movement for departure

3.2.2 Runway System

The Penang International Airport (PEN) is a major airport in Malaysia and serves the state of Penang and surrounding regions. The airport has a single runway system that is capable of accommodating a range of aircraft, including narrow-body and wide-body aircraft, refer Figure 3.3 for an understanding of the layout for the runway at PEN airport. The runway itself is a long, narrow rectangle "RUNWAY", extending across most of the layout's width. This runway is the backbone of the airport's operations, providing the necessary space for aircraft to take off and land. Based on Figure 3.4, as can see it the movement of the aircraft when it arrives or lands on the runway, and Figure 3.5 as can see the movement aircraft from the parking to the runway for departure. At both ends of the runway, there are sets of parallel lines, known as threshold markings. These markings are critical for pilots, indicating the beginning and end of the usable runway surface and helping to ensure safe landings and takeoffs.

The runway at Penang International Airport is designated as Runway 04/22, with a length of 3,353 meters(11,001 feet) and a width of 60 meters(197 feet). The runway is equipped with precision approach path indicators (PAPIs) and runway edge lights to assist pilots during takeoffs and landings. The taxiways of PEN which is a runway connected to the airport terminal and other facilities by a network of taxiways. These taxiways allow aircraft to maneuver around the airport and access various parking areas. The design for the apron is a single apron located in front of the terminal building that can accommodate up to 14 aircraft. The apron is equipped with various ground support equipment such as baggage carts, fuel trucks, and catering vehicles to service the aircraft. The runway system is equipped with various navigation aids such as runway centerline markings, touchdown zone markings, and taxiway edge lights. These aids help pilots to maintain the correct approach and ensure the safe and efficient movement of aircraft. The runway system at Penang International Airport is designed with various safety features such as runway end safety areas, blast pads, and arresting systems to prevent accidents and mitigate the consequences of any mishaps. These measures are critical to ensuring the safety of passengers, crew, and ground personnel.

3.2.3 The Arena Software

Arena Simulation Software is a powerful tool for conducting discrete event simulations (Dias et al., 2022). Some of the key features of Arena Simulation Software version 15.1 included the improved model-building tools Arena offers a number of tools for building simulation models, including a drag-and-drop interface and a wide range of built-in templates and objects. Version 15.1 includes a number of improvements to these tools, making it easier and faster to build complex models. Arena offers a wide range of options for analyzing simulation output, including built-in statistical analysis tools and customizable reporting options. Version 15.1 includes a number of new analysis options, including improved histograms and time series plots. It enhanced animation capabilities which include a powerful animation engine that allows users to visualize the operation of their simulation models in real time. Version 15.1 includes several enhancements to this animation engine, including improved graphics and the ability to animate multiple objects simultaneously. This software also enhanced integration with other software tools and Arena is designed to work seamlessly with other software tools, including Excel and MATLAB. Version 15.1 0includes improvements to these integrations, making it easier to import and export data between Arena and other software tools.

Arena uses SIMAN language constructs to represent the logic of the simulation model. The SIMAN language consists of two types of objects which are blocks and elements. Blocks are the basic logic objects that represent operations, such as *SEIZE, DELAY*, and *RELEASE*, while elements represent facilities, such as *QUEUE* and *RESOURCE.* The Arena software includes a variety of modules, which are the fundamental components of the modeling process. One such module is the *PROCESS* module, which models the process task of an entity. The *PROCESS* module is made up of SIMAN blocks and elements, such as *SEIZE, DELAY*, *RELEASE*, and *QUEUE*.

In the context of the Arena software, the modules can be classified into two categories: flowchart modules and data modules. Flowchart modules explain the process in the model and are connected to each other in some way. *CREATE, ASSIGN, PROCESS*, and *DISPOSE* are examples of flowchart modules that dynamically interact with each other as entities flow through the system. These modules represent the logical flow of the simulation model, from the moment an entity enters the system until it is disposed of. Data modules, on the other hand, do not have the same function as flowchart modules. Entities do not flow through the data modules. Instead, data modules are used to define the characteristics of specific process elements. They manipulate variables and other types of numerical values and expressions that interact with the whole model. Examples of data modules include *GLOBAL, ATTRIBUTE,* and *VARIABLE* modules. Although flowcharts and data modules have different functions, they are interconnected through mutual objects that they share. For example, a flowchart module may use a variable defined in a data module to determine the processing time of an entity.

In the implementation of the Arena software for this study, both flowcharts and data modules were used to develop the simulation model. The flowchart modules were used to model the logical flow of entities through the system, while data modules were used to define the characteristics of process elements and manipulate numerical values and expressions.

The arena is a flexible module-oriented computer simulation tool that allows modelers to develop simulation models of complex systems involving the flow of entities through various processes. The interface used to develop the model is like a canvas, where the modeler can drag and drop various modules, such as flowcharts and data modules, to construct the logic of the simulation model. Once the modeler has completed the model construction, Arena automatically translates all the flowcharts into SIMAN codes. These codes are then checked by Arena for any syntactic errors, both textual and graphical, and if any errors are detected, the debugging procedure are take place automatically. This automatic translation and error-checking process help to ensure the accuracy and reliability of the simulation model. It also saves time and effort for the modeler, as they do not need to manually translate the flowcharts into code or check for errors.

The Arena software provides a built-in function called Input Analyzer that can be used to process the input data used in developing the simulation model. Input Analyzer is a powerful tool that can be used to analyze and manipulate input data, such as arrival times, processing times, and other parameters, to create probability distributions that can be used in the simulation model. For this study, the data on inter-arrival times between vehicles was collected and processed using the Input Analyzer function to obtain a probabilistic expression for the arrival rate at specific junctions. This probabilistic expression was then used to model the arrival of vehicles in the simulation model. Using an Input Analyzer to process input data can help to ensure the accuracy and reliability of the simulation model, as it allows for the creation of realistic probability distributions based on real-world data. It also saves time and effort for the modeler, also does not need to manually calculate or estimate probability distributions themselves and the section explains the input data that used the Input Analyzer function.

Overall, Arena Simulation Software version 15.1 is a powerful and flexible tool for conducting discrete event simulations. Whether building a simulation model from scratch or analyzing complex simulation output data, Arena provides the tools and capabilities that are needed to get the job done.

3.2.4 Input Data in Modelling

As discussed in Section 3.1.4, creating a simulation model with Arena software required specific input data, such as the arrival rate. In this study, the inter-arrival time between aircraft at specific crossings was measured and analyzed using the Input Analyzer, a built-in tool of Arena software. The input analyzer generates a probabilistic expression, which is subsequently used to develop the model. Table 3.1 shows an output obtained from the input analyzer for the time between arrival. Note that the time between arrival is from a mix type of aircraft category. The simulation model is being developed using these input analyzers. See Figure 3.1 and Figure 3.2 for detailed output from the input analyzer which shows the fit distribution.

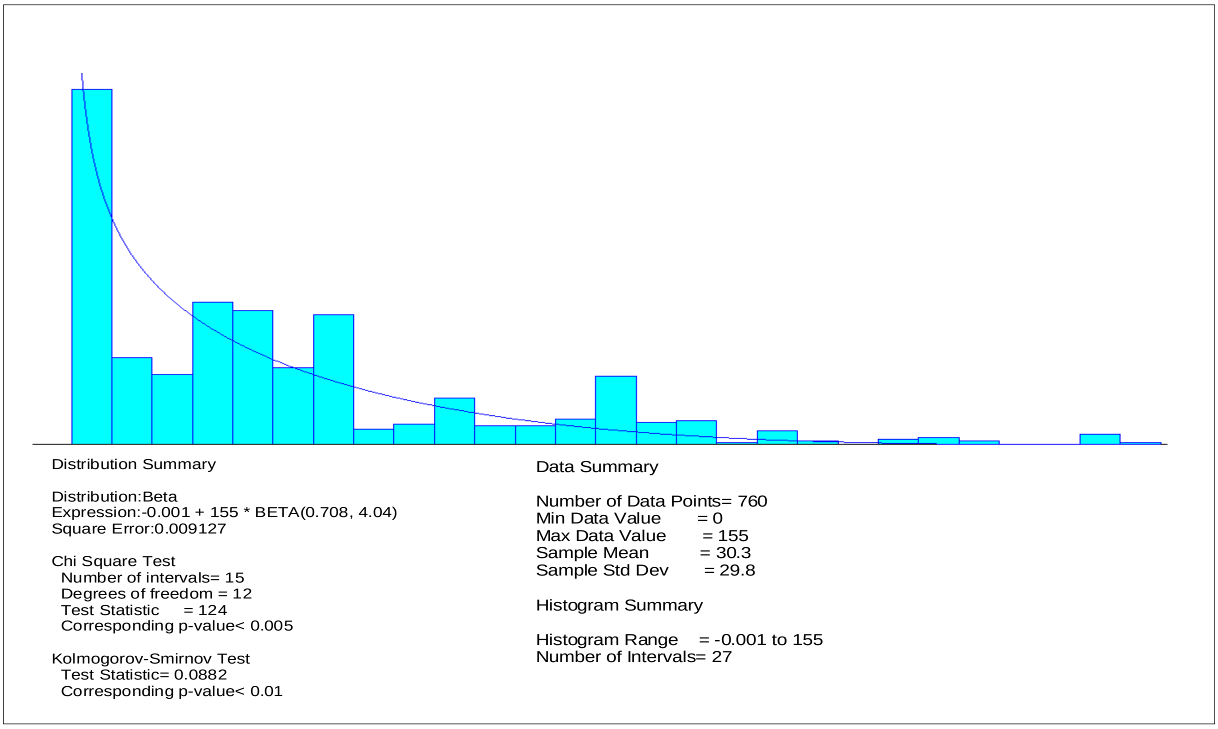

Figure 3.6 The Output from the Input Analyzer for January - March Data

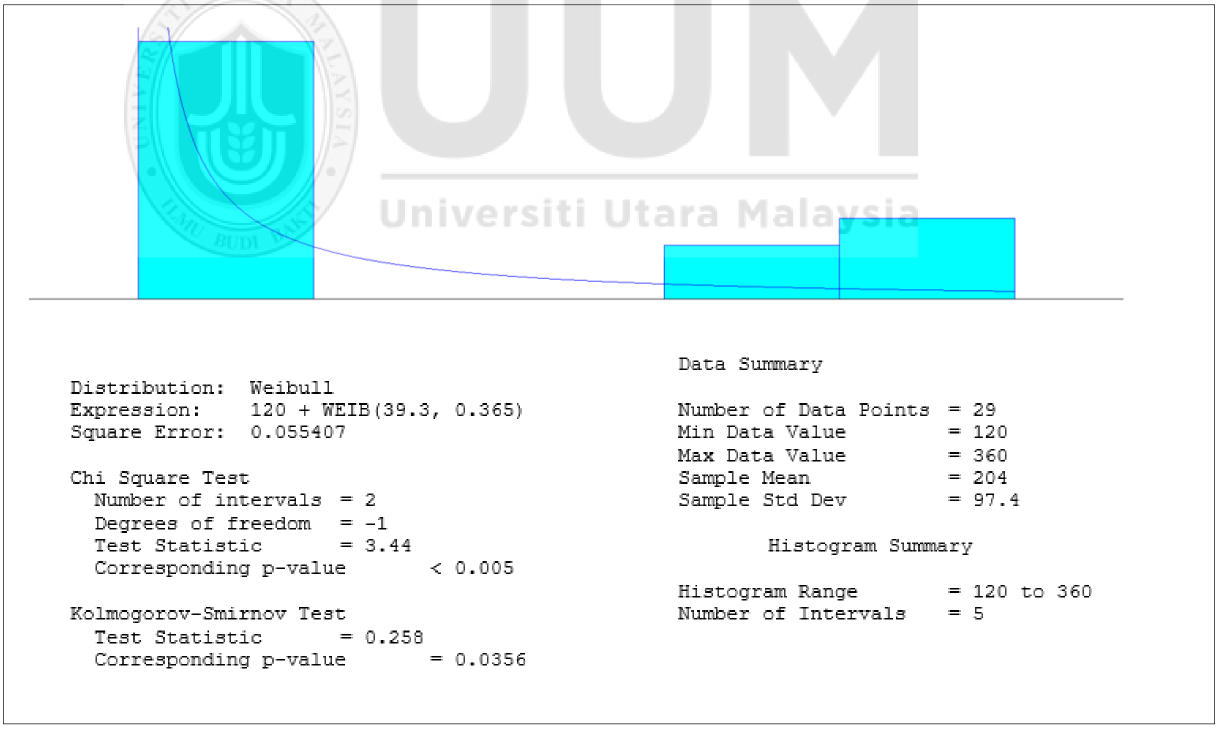

Figure 3.7: Output from Input Analyzer for November Data

Table 3.1
Output from Analyzer for Interarrival Distribution

Input Data	Distribution	
	January – March	November
Time between arrival	-0.001 + 155 * BETA(0.708, 4.04)	120 + WEIB(0, 0)

For this model of Arena, -0.001 + 155 * BETA(0.708, 4.04) is used for the basic model because beta distribution is flexible and can take various shapes depending on its parameters. It is bounded between 0 and 1, which is then scaled in this formula. Suitable for representing times that have a clear upper and lower bound and are not necessarily symmetric. It is often used in scenarios where arrival times are skewed.

3.2.5 Assumption in Developing the Model

1. Three types of aircraft are created: small, medium, and large.
2. Safe separation minima between aircraft are determined according to minimum separation times or distances for arriving and departing aircraft.
3. Landing and/or take-off queries are considered continuous until the end of the simulation replication.
4. Landing and take-off operations are carried out in one direction only. Changes in wind direction and wind intensity are not taken into account.

3.2.6 Assign the Arena Software

The development of a simulation model, or model translation, for PEN Airport's runway, is covered in this section. The process of constructing the model involves many modules. The list of modules concerned is presented in Table 4.2.

Table 3.2
List of modules used in developing ARENA

Module	Function
Create	Creating the aircraft
Station	Entity movement purpose
Assign	Assign type of aircraft category, separation time, and to enter or exit runway
Decide	To decide the distribution of aircraft categories, exit point, and enter or exit the runway.
Route	Connect one station to another station
Hold	Hold the aircraft at the runway and wait for the signal, as the ATC
Seize	To seize the resources(runway clear)
Release	Release the resources(runway clear) to allow the next aircraft to enter the runway.

Store	Parking aircraft
Delay	Parking time for aircraft
Unstore	Release aircraft from parking
Dispose	Exit point

An in-depth explanation of the model translation was explained in five sections which are the modeling of flight arrivals, modeling final approach, modeling runway events, the logic model for parking, and modeling for aircraft disposal.

a. The Modelling Flight Arrivals

A create module is used to create an aircraft. As shown in Table 3.1, provides the basis for the interval between aircraft arrivals. A station module is used to represent the arrival position, which is utilized to animate the model. Each aircraft is assigned a type size of aircraft which are small, medium, and large. It uses a decision module with N-way by Chance to describe the likelihood as shown in Figure 3.9 and the percentage of its value can be referred to in Table 3.3. Then, using an assignment module, each type of aircraft is given the appropriate attributes so that their flow logic can be controlled and their system performance can be evaluated. These consist of its system number, waiting time of final approach. Refer to Figure 3.8 for the logic process create aircraft and flight arrivals.

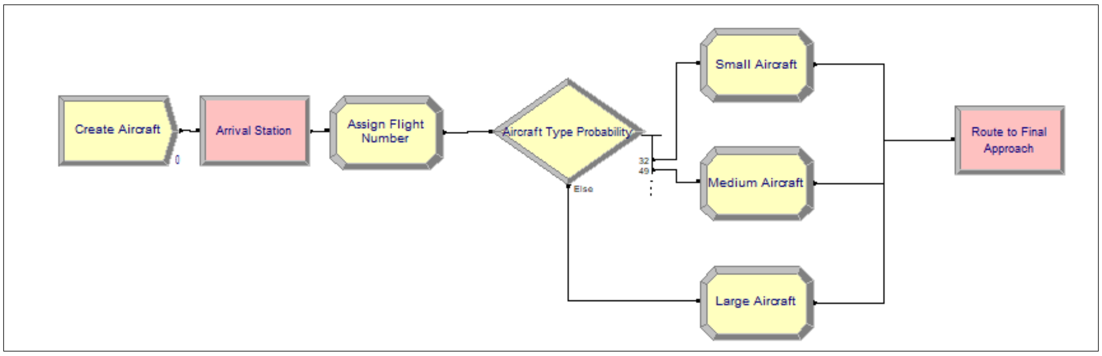

Figure 3.8: The modelling to create aircraft and flight arrivals

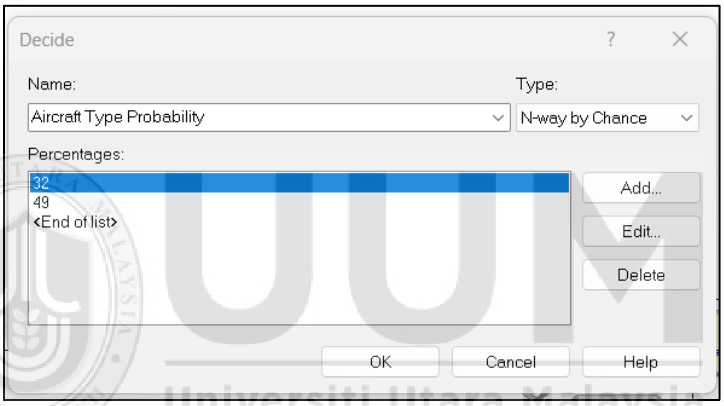

Figure 3.9: The condition probabilities for each entity based on aircraft type

Table 3.3
The percentage mix of Aircraft

Aircraft Category	Frequency	Percentage (%)	Probability	Cumulative Probability
Small	247	32	0.32	0.32
Medium	373	49	0.49	0.81
Large	141	19	0.19	1.0000
Total	761	100	1.0000	-

b. The Modelling for Final Approach

This modelling part is responsible for events that occur before landing. Some extra attributes, such as the succeeding aircraft type and arrival separation time, must be connected to the aircraft.

	Following aircraft						
Proceeding aircraft	Aircraft Type	Lightweight	Medium	Heavy	Lightweight	Medium	Heavy
	Lightweight	3	3	3	98	74	74
	Medium	4	3	3	138	74	74
	Heavy	6	5	4	167	114	94
		Minimum distance separation (NM)			The minimum time separation (s)		

Figure 3.10: Based on the journal Air Traffic Control Approach Procedural Separation Assessment Mode (Tang, 2014)

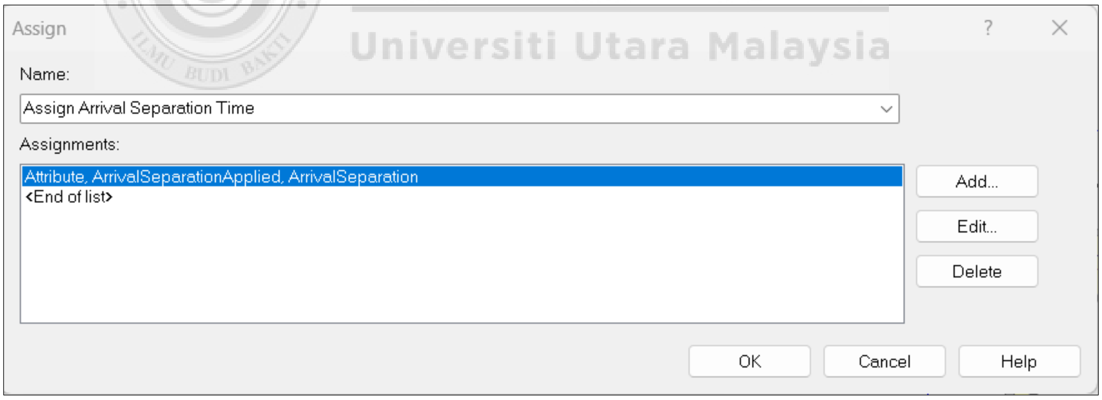

Figure 3.11: Condition check for separation time

In Arena, matrix data can be stored in an array variable. This separation time must only be stated if the aircraft is being held in a queue because another aircraft uses the runway or waits for its turn to land. A hold module is used to keep aircraft in place. Once released, the aircraft is determined by separation time that is stored in an array variable based on data in Figure 3.10, followed by the entity for small aircraft used the measurement for lightweight, for medium aircraft used the medium measurement and for large aircraft used the heavy measurement.

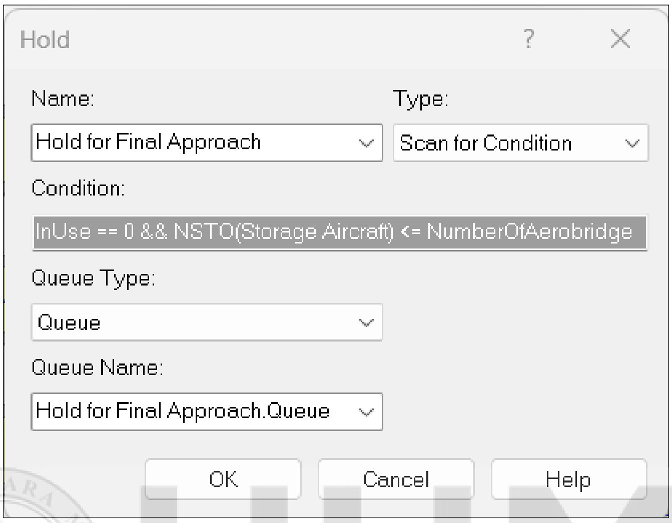

Figure 3.12: Hold logic before access final approach

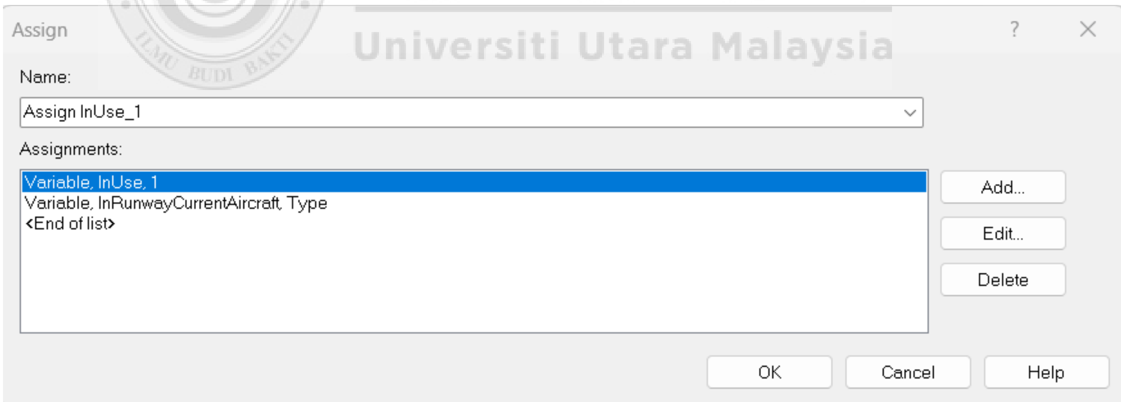

Figure 3.13: Condition check for availability of runway

In addition, the aircraft should be held if there is no aerobridge or parking space available which can be referred to in Figure 3.14 in the assigned module. For Figure 3.13, if the conditions are not met, the aircraft must wait for a signal to commence landing, and Figure 3.14 shows outlines the logic process for modeling the final approach.

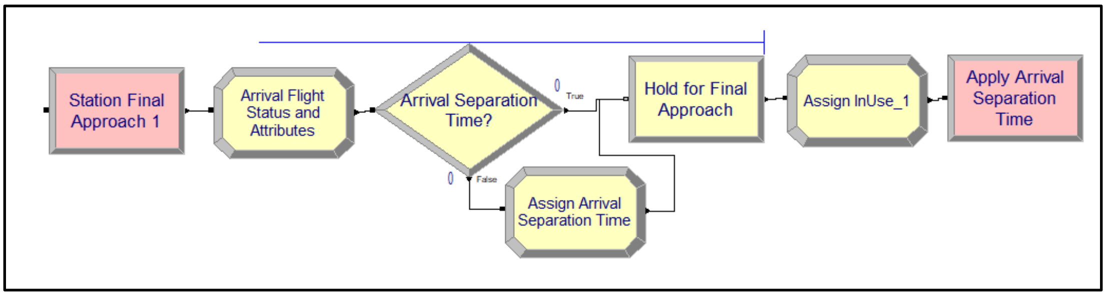

Figure 3.14: The modelling for the final Approach

c. The Runway Event

After the separation time has elapsed, the aircraft proceeds to Station Enter Runway to seize the runway. Figure 4.9 shows the logic process in runway events either from departure or landing to access for the final approach. In this station, the arrival or departure time is retrieved and assigned to appropriate properties. The aircraft is then delayed to reflect runway occupational landing or take-off time. When the occupational time is up, the aircraft releases the runway, making it available to other aircraft. Typically, the arriving aircraft is given priority on the runway.

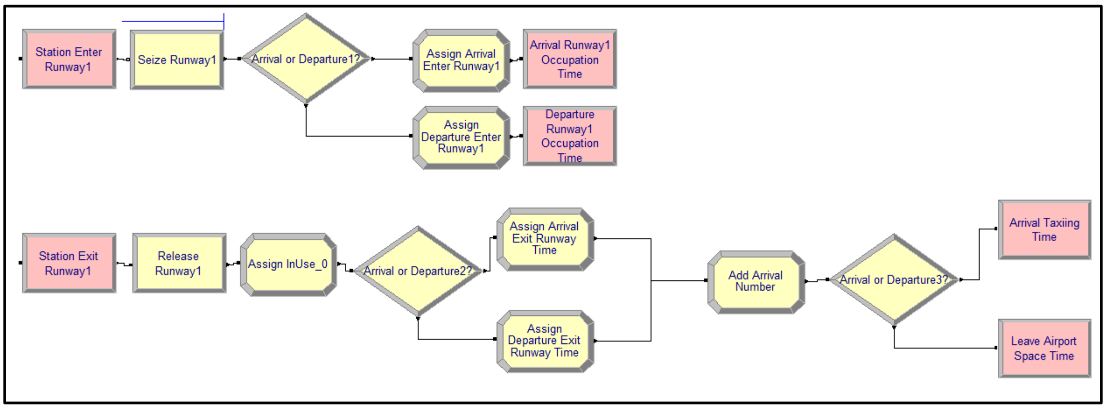

Figure 3.15: Runway event for departure and arrival

d. The Logic Model for Parking

After a delay due to the taxiing time, the aircraft arrives at the parking space. The purpose of the Parking Modelling subsection is to model events on site. Parked aircraft are stored in the store module. The storage module named Park Aircraft is used to provide a place for the stationary aircraft symbol to be animated forward in time. The execution time of the event is represented by every 60 minutes. Once the parking time is over, the aircraft moves to the taxiway according to the specified taxi time. (see Figure 3.16)

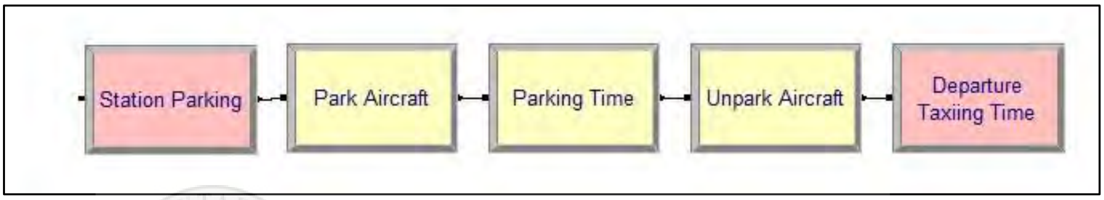

Figure 3.16: The modelling of parking

e. Modelling for Aircraft Dispose

Before departure, the aircraft must ensure that no other aircraft is on the runway and hold for final access. The flight status is set to 2 to indicate the status of the departure flight. Then, the type of this aircraft is changed to a variable Departure Current Aircraft, allowing it to be assigned the attribute of the next aircraft. This combination is used to calculate the departure of separation time. Then utilize a decision module to determine whether or not to employ the separation time, based on the runway being used and the number of flights waiting for the final approach. Based on Figure 3.17, the modelling for system disposal, means that the aircraft had completed the simulation and the system number out for aircraft was recorded.

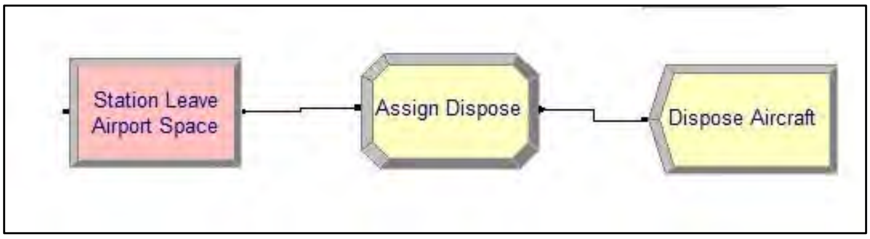

Figure 3.17: Modelling for dispose

All of the information was subsequently gathered and transformed into a computer-recognizable form using the Arena software, as previously stated. The model was created as closely to the real system as feasible. After thoroughly developing the simulation model, there was still one step to be completed before the basic run could be done. This is an important step in setting up the simulation run. Figure 3.18 shows the run setup for the basic model.

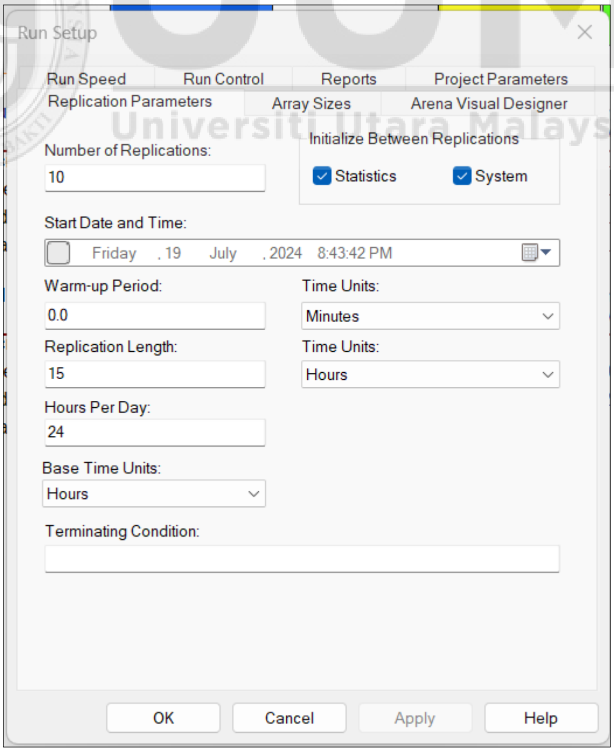

Figure 3.18: Run Setup for model simulation

The higher replications lead to more precise results. The number of replications is set to ten replications. The duration of the simulation run is set to 15 hours since the data collected is usually from 7 am until 10 pm. The statistics and system are initialized between replications, which means that at the start of each replication run, all values are reset to their original state. The outputs of the simulation run are addressed in the following chapter.

CHAPTER FOUR
OUTPUT ANALYSIS AND FINDINGS

4.0 Overview

The model translation phase was discussed in the previous chapter. The next step in the discrete event simulation methodology is model verification and model validation. In this chapter, those steps are explained. Once the model had been verified, three scenarios were tested and also discussed in this chapter.

4.1 Basic Model

In section 3.2.6, the process for setting up the basic model of the PEN Airport runway using Arena software is outlined. This section provides a detailed explanation of the model's configuration. Additionally, section 3.1.6 addresses the validation and verification of this basic model. The simulation was conducted for 15 replication lengths, with data collected on the average time of the first flight arrival and the last flight departure for each day. To ensure accuracy, the model was run with 10 replications to compare the average number of aircraft in the system with the average aircraft count. For this Basic Model output refer to Section 4.2 which discusses the comparing between the changes factor of interarrival will affect the value of system number out.

4.2 Model Experimentation

A total of three experiments were conducted, and each of these experiments was called a scenario. All these scenarios which had led to several hypotheses were designed based on the suggestions from previous researchers when conducting the simulation for runway capacity. The hypotheses became the foundation for each of the scenario designs.

Based on the observation, at a certain period, the aircraft before the final approach to the runway or landing are often stuck due to the limitation of the capacity runway causing a bottleneck. The experimentations were conducted based on the intention to improve this problem. The next section discusses the first scenario.

4.2.1 Scenario 1

Increasing the Scaling Factor: To proportionally increase the time between arrivals, the scaling factor can increased from 155 to an upward value. For instance, to achieve a 20% reduction in the meantime, the new scaling factor can be calculated as follows:

The original Time Between Arrivals = -0.001 + 155 * BETA(0.708, 4.04)

i. The original scaling factor is 155. To increase it by 20%, multiply it by 1+0.20 (since 20% increases mean retaining 80% of the original value):

   New Scaling Factor = 155 * (1+0.20) = 155 * 1.20 = 186

ii. Substitute the new scaling factor into the formula:

   Replace the original scaling factor with the new scaling factor in the formula

   New Time Between Arrivals for Scenario 1 = -0.001 + 186 * BETA (0.708, 4.04)

Table 4.1
New Distribution used in Scenario 2

Type of Distribution	Value
Beta	-0.001 + 186 * BETA(0.708, 4.04)

The new distribution in Table 4.2 was used to replace the value for time between arrival in the Basic Model. By increasing the factor between arrivals, tested that it will affect the system number out of aircraft and the waiting time for aircraft to access for final approach. A detailed explanation of the findings is explained in Section 4.2.

4.2.2 Scenario 2

Decreasing the Scaling Factor: To proportionally decrease the time between arrivals, the scaling factor can be reduced from 155 to a lower value. For instance, to achieve a 20% reduction in the meantime, the new scaling factor can be calculated as follows:

The original Time Between Arrivals = -0.001 + 155 * BETA(0.708, 4.04)

i. The original scaling factor is 155. To reduce it by 20%, multiply it by 1-0.20 (since 20% reduction means retaining 80% of the original value):

   New Scaling Factor = 155 * (1-0.20) = 155 * 0.80 = 124

ii. Substitute the new scaling factor into the formula:

   Replace the original scaling factor with the new scaling factor in the formula

New Time Between Arrivals for Scenario 1 = -0.001 + 124 * BETA (0.708, 4.04)

Table 4.2
New Distribution used in Scenario 2

Type of Distribution	Value
Beta	-0.001 + 124 * BETA(0.708, 4.04)

The new distribution in Table 4.1 was used to replace the value for time between arrival in the Basic Model. By reduction, the factor between arrivals, tested that it will affect the system number out of aircraft and the waiting time for aircraft to access for final approach. A detailed explanation of the findings is given in Section 4.2.

4.2.3 Scenario 3

In Scenario 3, the arrival process is set manually based on time distribution. If the scenario for time between arrivals is set to be random every 10 minutes, this means that arrivals followed a uniform distribution between 0 and 10 minutes. This approach simplifies the arrival process and ensures variability within a fixed range.

Table 4.3
New interarrival for Scenario 3

Type of Distribution	Value (minutes)
Random	10

4.3 Comparing Basic Model with Each Scenario

In this section further explanation about the finding of each scenario. For Scenario 1 & Scenario 2 the factor that chooses the value 20% increases and decreases the factor value because some studies found that picking 20% as the threshold is a strategic choice for testing is optimal to avoid overfitting (Gholamy et al., 2018). Based on Introduction to Continous Distribution, 2020 where detailed data on process variability is limited, or where it is assumed that all outcomes within a range are equally likely, the use of a uniform distribution can be appropriate so Scenario 3 uses the uniform distribution as part of testing the findings. This approach is often used in early-stage modeling to simplify assumptions and gain initial insights into system behavior. Notably, the final approach in this study refers to the aircraft start to enter the runway either to depart or landing.

4.3.1 Basic Model vs Scenario 1

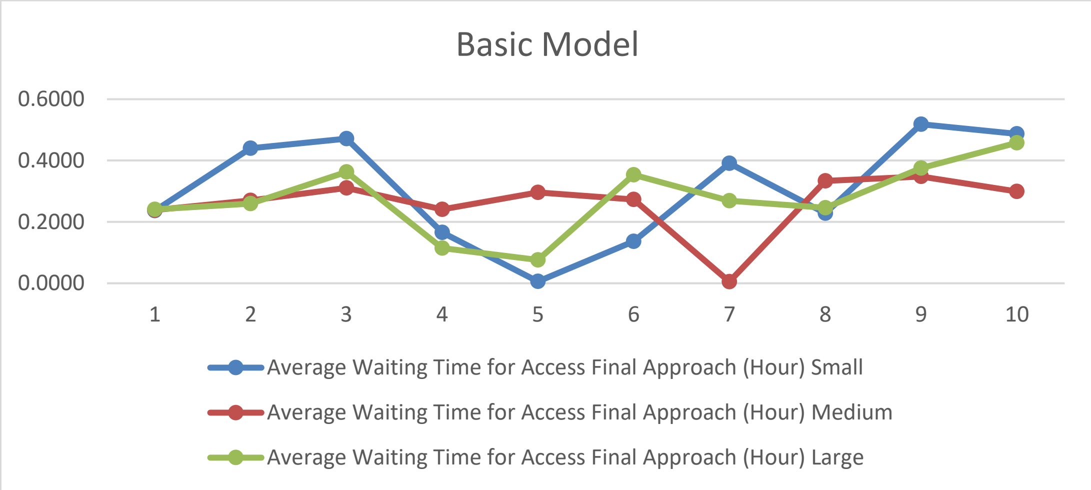

Figure 4.1: The output of each test for the Basic Model

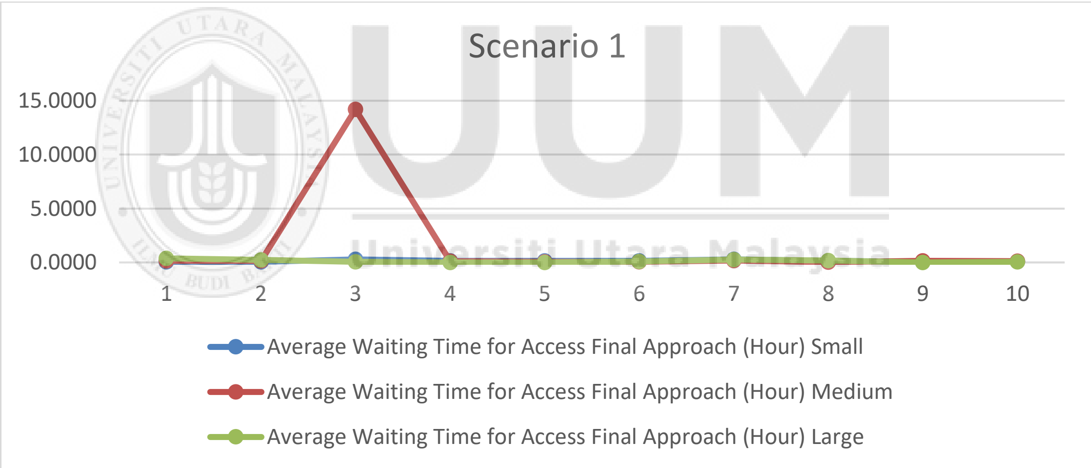

Figure 4.2: The output of each test for Scenario 1

Based on Figure 4.1 and Figure 4.2, shows the comparison between the Basic Model and Scenario 1 reveals significant differences in average waiting times across various aircraft types.

For small aircraft, Scenario 1 consistently outperforms the Basic Model by significantly reducing average waiting times. Specifically, Scenario 1 achieves waiting times ranging from 0.0466 to 0.2838 minutes, with an overall mean of approximately 0.1416 minutes. In contrast, the Basic Model exhibits a wider range of 0.0059 to 0.5184 minutes, with an average of 0.3135 minutes. These findings indicate that Scenario 1 is more effective in minimizing delays for small aircraft.

When evaluating medium aircraft, Scenario 1 generally shows superior performance compared to the Basic Model by lowering average waiting times. However, an outlier observed in Test 3 skews the data, resulting in a significantly higher average waiting time of 14.1918 minutes for that test. Excluding this outlier, Scenario 1 maintains an average waiting time of approximately 0.1188 minutes, which is notably lower than the Basic Model's average of 0.2811 minutes. While Scenario 1 shows potential for reducing delays, its stability may be compromised under certain conditions.

For large aircraft, Scenario 1 again exhibits enhanced performance, with average waiting times ranging from 0.0000 to 0.3798 minutes and a mean of approximately 0.1296 minutes. By comparison, the Basic Model shows a range of 0.0762 to 0.4578 minutes, with an average waiting time of 0.2785 minutes. These results further highlight Scenario 1's effectiveness in decreasing delays for large aircraft.

4.3.2 Basic Model vs Scenario 2

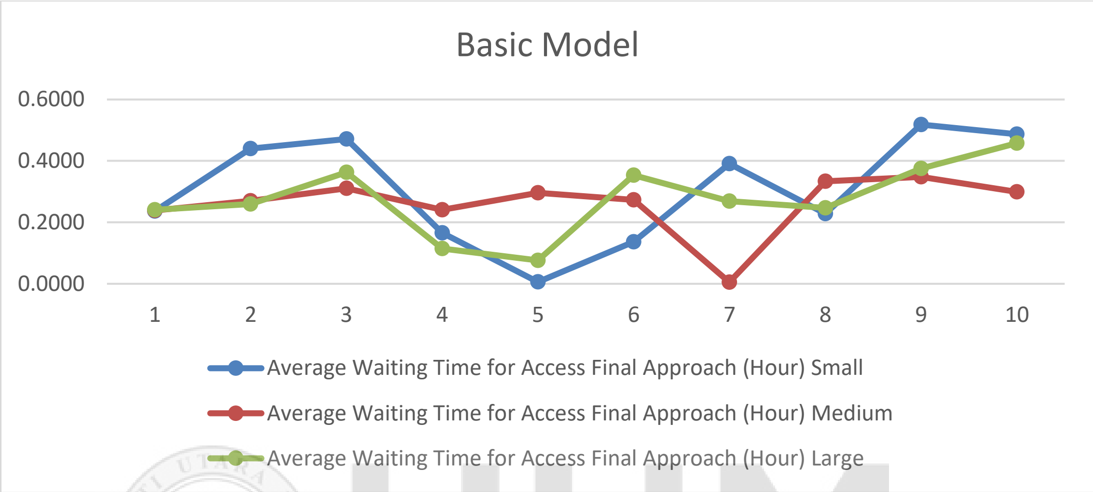

Figure 4.3: The output of each test for the Basic Model

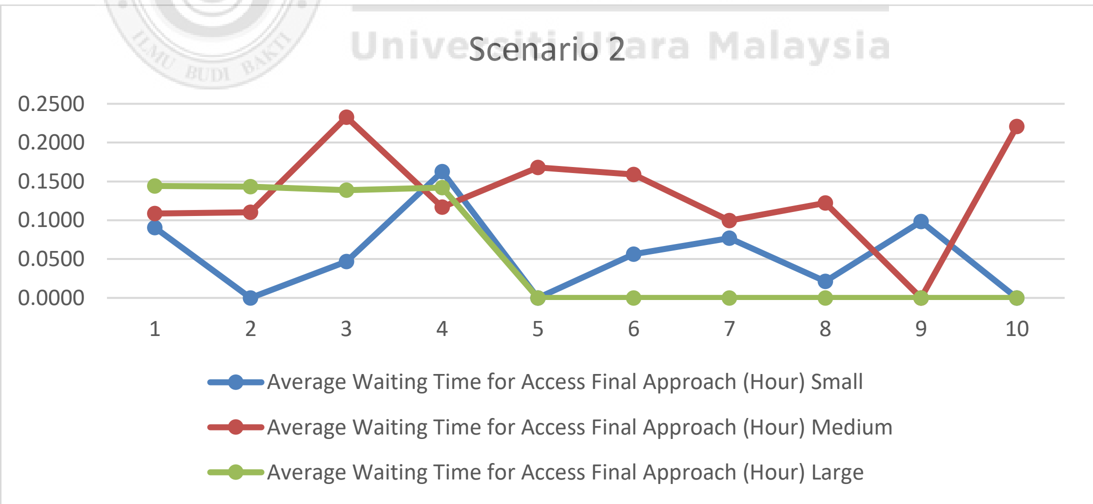

Figure 4.4: The output of each test for Scenario 2

The comparison between the Basic Model and Scenario 2 reveals notable differences in average waiting times across different aircraft types, highlighting in Figure 4.3 and Figure 4.4 the impact of the new scenario on operational efficiency.

The average waiting time for small aircraft in the Basic Model ranges from 0.0059 to 0.5184 minutes, with a mean value of 0.3135 minutes. In contrast, Scenario 2 shows a significant reduction in waiting times, with values ranging from 0.0000 to 0.1626 minutes and an average of 0.0553 minutes. These results indicate that Scenario 2 is more efficient, substantially reducing waiting times for small aircraft compared to the Basic Model.

For medium aircraft, the Basic Model exhibits waiting times between 0.0053 and 0.3480 minutes, with an average of 0.2811 minutes. Scenario 2, however, demonstrates improved performance with reduced waiting times ranging from 0.0000 to 0.2328 minutes and an average of 0.1339 minutes. This suggests that Scenario 2 not only lowers waiting times but also provides more consistency across medium aircraft operations.

The Basic Model records waiting times for large aircraft ranging from 0.0762 to 0.4578 minutes, with an average of 0.2785 minutes. Scenario 2 further reduces these waiting times, showing a range of 0.0000 to 0.1442 minutes and an average of 0.0568 minutes. The data indicates that Scenario 2 offers a significant improvement in efficiency for large aircraft, with much lower average waiting times compared to the Basic Model.

4.3.3 Basic Model vs Scenario 3

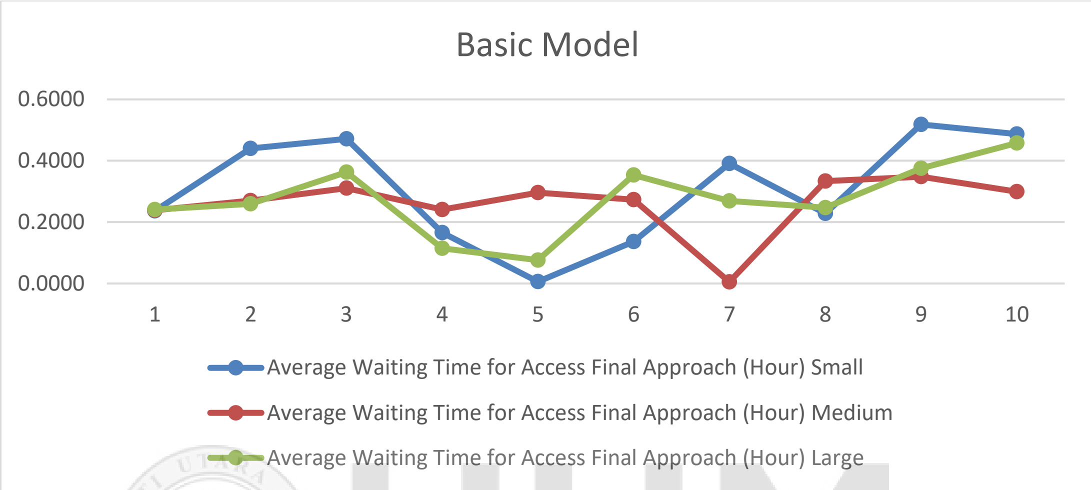

Figure 4.5: The output of each test for the Basic Model

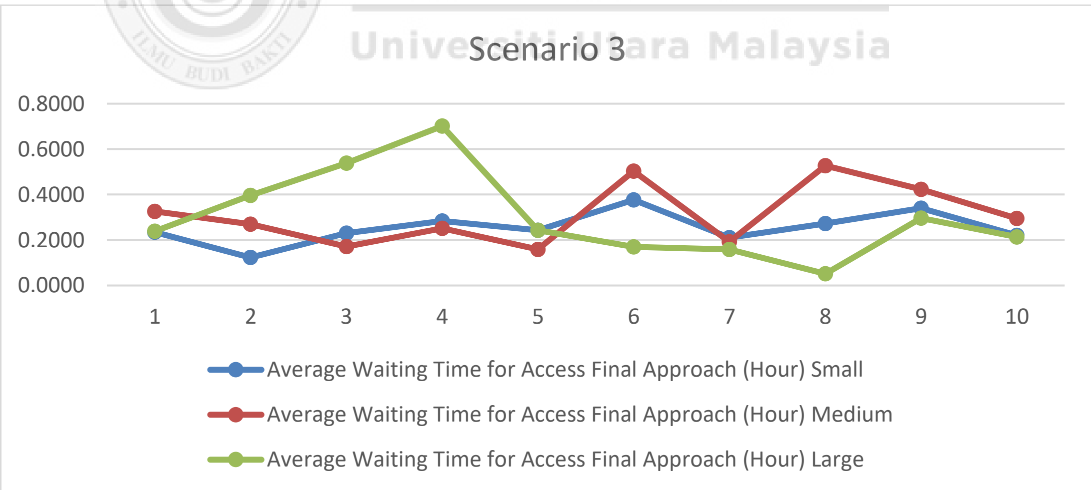

Figure 4.6: The output of each test for Scenario 3

The comparison between the Basic Model and Scenario 3 reveals significant differences in average waiting times for various aircraft types based on the Figure 4.5

and Figure 4.6 in order emphasizing the impact of Scenario 3 on operational efficiency.

In the Basic Model, the waiting times for small aircraft range from 0.0059 to 0.5184 minutes, with an average of 0.3135 minutes. Scenario 3, however, demonstrates improved performance, with waiting times ranging from 0.1230 to 0.3768 minutes and an average of 0.2536 minutes. These findings indicate that Scenario 3 provides a reduction in waiting times and offers more consistent performance for small aircraft compared to the Basic Model.

For medium aircraft, the Basic Model shows waiting times between 0.0053 and 0.3480 minutes, with an average of 0.2811 minutes. Scenario 3, in contrast, results in higher and more variable waiting times, ranging from 0.1590 to 0.5274 minutes, with an average of 0.3157 minutes. This analysis suggests that the Basic Model achieves greater efficiency for medium aircraft, delivering lower and more stable waiting times compared to Scenario 3.

The Basic Model records waiting times for large aircraft ranging from 0.0762 to 0.4578 minutes, with an average of 0.2785 minutes. Scenario 3 shows a broader range, from 0.0513 to 0.7014 minutes, with a slightly higher average of 0.3007 minutes. These results highlight that the Basic Model performs better for large aircraft, providing shorter and more consistent waiting times relative to Scenario 3.

Table 4.4
Summary of Each Scenario for Average Waiting Time

Aircraft Type	Scenario 1	Scenario 2	Scenario 3	Conclusion
Small	Waiting Times: 0.0000 to 0.2838 minutes	Waiting times: 0.0000 to 0.0906 minutes	Waiting times: 0.1230 to 0.3768 minutes	Scenario 2 is more effective, offering the lowest average waiting times.
Medium	More variable, some extreme values but generally lower averages	Waiting times: 0.0000 to 0.2338	Waiting times: 0.1590 to 0.5274 minutes, higher average compared to Scenario 1	Scenario 2 shows better performance with lower and more consistent waiting times.
Large	Waiting times: 0.0000 to 0.3798 minutes, lower averages than Scenario 3 and Basic Model	Waiting times: 0.0000 to 0.1442 minutes	Waiting times: 0.0513 to 0.7014 minutes, higher averages	Scenario 2 is the most effective, providing the lowest average and most consistent waiting times.

The analysis of the three scenarios, as compared to the basic model, reveals distinct variations in the average waiting times across different aircraft types. The findings are presented in Table 4.4, which summarizes each scenario's performance in reducing waiting times for small, medium, and large aircraft.

4.4 Analysis Discussion and Summary

A model was developed using Arena software in order to represent the real-world situation at PEN airport’s runway . The verification step was accomplished by having built the model correctly. An animation presentation was used to visually check the model by tracing a single entity flow throughout the model. In order to develop a correct model, a validation process was implemented where the validity level for the runway must be below than ten percent, which must pass the model's accuracy requirement.

Having passed the validity level test, a basic model was officially developed. Using the basic model, a total of three scenarios were designed. The aim was to find utilization usage for runway capacity, by having the lowest total of the average waiting time. Table 4.4 shows the comparison of the utilization of the runway between all the scenarios. In this section, to calculate the percentage improvement between the Basic Model and each scenario based on the average waiting time, we first need to calculate the average waiting times for each category (Small, Medium, Large);

$$Percentage\ Improvement = \left(\frac{Basic\ Model\ Average - Scenario\ Average}{Basic\ Model\ Average}\right)$$

i. **Basic Model Average Waiting Times:**

Table 4.5
Average Waiting Time for Basic Model

No. of Replication	Average Waiting Time (minutes)		
	Small Aircraft	Medium Aircraft	Large Aircraft
1	0.2369	0.2387	0.2409
2	0.4404	0.2700	0.2598
3	0.4716	0.3108	0.3630
4	0.1662	0.2412	0.1146
5	0.0059	0.2958	0.0762
6	0.1368	0.2730	0.3534
7	0.3912	0.0053	0.2694

8	0.2286	0.3342	0.2466
9	0.5184	0.3480	0.3756
10	0.4866	0.2994	0.4578
Sum	2.6976	2.7364	2.5363
Average Time (minutes)	0.2698	0.2736	0.2536

Based on table 4.5, shows the value of the basic model for each replication test on waiting time.

ii. Scenario 1 Average Waiting Times:

Table 4.6
Average Waiting Time for Scenario 1

No. of Replication	Average Waiting Time (minutes)		
	Small Aircraft	Medium Aircraft	Large Aircraft
1	0.0466	0.1566	0.3798
2	0.0595	0.1409	0.2424
3	0.2838	14.1918	0.0509
4	0.1428	0.1092	0.0000
5	0.1590	0.0600	0.0000
6	0.1386	0.0708	0.1026
7	0.2838	0.1932	0.2658
8	0.1446	0.0277	0.1824
9	0.0583	0.1380	0.0000
10	0.0990	0.1134	0.0708
Sum	0.0466	0.1566	0.3798

Average Time (minutes)	0.1416	1.5202	0.1295

Based on table 4.6, shows the value of scenario 1 for each replication test on waiting time.

iii. Scenario 2 Average Waiting Times:

Table 4.7
Average Waiting Time for Scenario 2

No. of Replication	Average Waiting Time (minutes)		
	Small Aircraft	**Medium Aircraft**	**Large Aircraft**
1	0.0906	0.1086	0.1442
2	0.0000	0.1104	0.1432
3	0.0467	0.2328	0.1387
4	0.1626	0.1170	0.1420
5	0.0000	0.1680	0.0000
6	0.0563	0.1590	0.0000
7	0.0768	0.0996	0.0000
8	0.0215	0.1224	0.0000
9	0.0984	0.0000	0.0000
10	0.0000	0.2208	0.0000
Sum	0.5529	1.3386	0.5681
Average Time (minutes)	0.0553	0.1339	0.0568

Based on table 4.7, shows the value of scenario 2 for each replication test on waiting time.

iv. **Scenario 3 Average Waiting Times:**

Table 4.8
Average Waiting Time for Scenario 3

No. of Replication	Small Aircraft	Medium Aircraft	Large Aircraft
1	0.2352	0.3258	0.2394
2	0.1230	0.2694	0.3966
3	0.2304	0.1716	0.5382
4	0.2838	0.2508	0.7014
5	0.2436	0.1590	0.2424
6	0.3768	0.5028	0.1698
7	0.2100	0.1920	0.1590
8	0.2724	0.5274	0.0513
9	0.3396	0.4236	0.2958
10	0.2208	0.2946	0.2136
Sum	0.2352	0.3258	0.2394
Average Time (minutes)	0.2536	0.3117	0.3008

Based on table 4.8, shows the value of scenario 3 for each replication test on waiting time.

Percentage Improvement Calculation:

Then calculate the percentage of improvement based on the formula.

Table 4.9
Summary Table of Each Scenario

Scenario	Average Waiting Time(Minutes)			Total Reduction from Basic Model(Minutes)			Percentage Performance		
	Small	Medium	Large	Small	Medium	Large	Small	Medium	Large
Basic Model	0.2698	0.2736	0.2536	-	-	-	-	-	-
1	0.1416	1.5202	0.1295	0.1282	-1.2466	0.1241	48%	-456%	49%
2	0.0553	0.1339	0.0568	0.2145	0.1397	0.1968	80%	51%	78%
3	0.2536	0.3117	0.3008	0.0162	-0.0381	-0.0472	6%	-14%	-19%

Refer to Table 4.9 for a summary of the percentage performance between the basic model and each scenario. The analysis of Scenario 2, where the interarrival rate is decreased, clearly demonstrates a marked improvement in the average waiting times for aircraft across all categories. The data suggests that implementing a decreased interarrival rate is particularly effective in reducing delays for small and large aircraft, with improvements of 80% and 78%, respectively. Medium-sized aircraft also benefit, though to a lesser extent, with a 51% improvement. These findings highlight the potential of strategic adjustments in arrival rates to optimize the flow of aircraft, thus enhancing overall operational efficiency at the final approach stage.

CHAPTER FIVE
CONCLUSION

5.1 Overview

The purpose of this dissertation is to explore and analyze a particular research This chapter provides an overview of the entire dissertation and its purpose. It begins with a summary of the dissertation's content, followed by a discussion of the study's contributions in Section 5.2. The limitations of the study are then discussed in Section 5.3. Finally, the last section of this chapter presents recommendations for future research.

5.2 Conclusion

This study successfully developed a Discrete Event Simulation (DES) model to evaluate and optimize the runway capacity at PEN International Airport, focusing on the critical aspect of runway congestion as part of the broader airport capacity. Airport capacity encompasses a wide range of factors including runway congestion, terminal capacity, parking facilities, air traffic management, security protocols, and overall operational efficiency. Managing these aspects is essential to meet the growing demand for air travel, and this study highlights runway congestion as a crucial element within this complex system.

The first sub-objective of the study was to evaluate the performance of PEN's runway capacity during peak hours. The findings revealed significant insights into the congestion levels at the runway and overall utilization of the runway. This evaluation identified key periods where the runway is most strained, highlighting potential bottlenecks that need to be addressed to improve efficiency.

For the second sub-objective, a detailed what-if analysis was conducted to explore various scenarios that could impact runway capacity. This analysis allowed for the testing of different operational parameters such as increased flight frequency, varied aircraft sizes, and alternative scheduling strategies. For this study, the scenarios are tested by changes in the value of interarrival and the result of findings can be referred to in Chapter 4 and the best scenario showed that small aircraft accounted for 77.3%, medium aircraft for 48.8%, and large aircraft for 72.4% of the total average waiting time. The flexibility of the DES model enabled the exploration of these scenarios without disrupting real-world operations, providing a safe and effective way to understand the implications of each variable.

Addressing the third sub-objective, the study proposed alternative scenarios and strategies to improve the airport's development plans and operational policies. These recommendations focused on optimizing runway utilization, reducing delays, and enhancing overall efficiency. The proposed solutions are particularly relevant as they align with the need for strategic planning and substantial investments in airport infrastructure, as well as the incorporation of cutting-edge technologies to enhance efficiency and expand capacity.

Moreover, the study underscored the importance of a unified approach that balances capacity expansion with environmental considerations, such as minimizing noise pollution and emissions and ensuring sustainable development. Collaboration among government authorities, airlines, and regulatory bodies is essential to navigate the complex regulatory landscape, ensuring that both efficiency and safety are optimized in airport operations.

In conclusion, this study not only fulfilled its main objective by developing a reliable and accurate simulation model but also provided valuable insights and recommendations for improving runway capacity at PEN International Airport. The research contributes significantly to the strategic planning and long-term development of the airport, ensuring its ability to meet future demands for air travel while maintaining a commitment to environmental sustainability and passenger satisfaction. The application of ARENA Software using the DES technique in this study demonstrates its utility in safely testing and optimizing airport operations, making it a crucial tool for future airport capacity planning and management.

5.3 Contribution of the Study

This section discusses the contribution of this study to improving single runway capacity during peak hours.

1. **Simulation Model Development:** The development of simulation models allows for testing specific modifications to the runway without needing to apply them in real-world scenarios. This approach saves cost, time, and energy.
2. **Guidelines for Runway Capacity Utilization:** The findings of this study can provide guidelines for relevant parties on how to better utilize runway capacity, leading to more efficient traffic management.

5.4 Limitations

Airport capacity estimation and delay analysis are crucial for managing increasing air traffic demands. Simulation models, particularly those using Arena software, have emerged as effective tools for evaluating runway capacity and aircraft movements (Zou et al, 2014; Sadono et al, 2021). These models can incorporate various factors such as fleet mix, exit way locations, and taxiway configurations, providing more realistic representations of airport operations compared to traditional analytical approaches (Zou et al, 2014; Ignaccolo, 2003). While queuing theory can offer rough estimates, simulation models are preferred for congested airports or when more detailed system behavior analysis is required (Ignaccolo, 2003; Thiagaraj & Seshaiah, 2014).

However, The process of creating a simulation model involves replicating the current real-world circumstances. The interactions in the actual system should be reflected in the model's development. However, because of the unpredictable and random behaviors, it can occasionally be a very difficult task. Both human error and the software used to create the simulation model itself have various shortcomings.

5.5 Recommendations and Future Work

This section discusses several suggestions to extend this study in order to expand the impact degree resulting in a better contribution.

1. **Simulation During Peak Times:** The current study focuses exclusively on peak hour traffic during weekdays at the end of the working day. To broaden the scope, future research could include simulations during peak hours at the beginning of the working day on weekdays, as well as during weekends.

2. **Variation in Aircraft Speed:** In this study, the aircraft's speed is assumed to be constant, based on an average value. Future studies could explore the effects of varying speeds for different types of aircraft, which would provide a more comprehensive understanding of the dynamics involved.

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APPENDIX A(1)

Identifier	Value
large.NumberIn	22.000
large.NumberOut	22.000
medium.NumberIn	47.000
medium.NumberOut	46.000
small.NumberIn	25.000
small.NumberOut	21.000
Runway1.NumberSeized	183.00
Runway1.ScheduledUtilization	.20333
System.NumberOut	89.000

APPENDIX A(2)

Day	Number of Aircraft
1	93
2	95
3	92
4	94
5	96
6	93
7	95
8	94
9	93
10	95
11	94
12	92
13	96
14	94
15	93
16	95
17	92
18	94
19	96
20	93
21	95
22	94
23	92
24	96
25	94
26	93
27	95
28	92
29	94
30	96
31	93
32	95
33	94
34	92
35	96
36	93
37	95
38	94
39	92
40	96

41	93
42	95
43	94
44	92
45	96
46	93
47	95
48	94
49	92
50	96
51	93
52	95
53	94
54	92
55	96
56	93
57	95
58	94
59	92
60	96
61	93
62	95
63	94
64	92
65	96
66	93
67	95
68	94
69	92
70	96
71	93
72	95
73	94
74	92
75	96
76	93
77	95
78	94
79	92
80	96
81	93
82	95
83	94
84	92

85	96
86	93
87	95
88	94
89	92
90	96

SUM	8460
Count Days	90

Average	94