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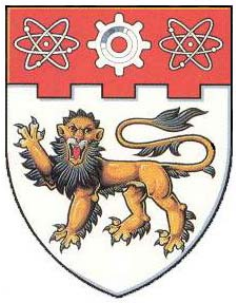
SIMULATION BASED DECISION SUPPORT

FOR AIRPORT LANDSIDE CAPACITY PLANNING



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A final year thesis

Presented to the Nanyang Technological University

in partial fulfillment of the

requirements for the

Degree of Masters of Engineering

Nanyang Technological University

2008

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ABSTRACT

Airport landside capacity planning formulates the amount of resources required for passengers processing in an airport terminal. This is a complex task because passenger volume and demand for resources do not have a definite relationship. Many methods have been proposed for airport landside capacity planning. However, some of these methods are too complicated to apply whereas the ones that are easy to apply often could not accurately model the stochastic and dynamic nature of an airport's landside.

This study developed a framework for a simulation based Decision Support System (DSS) to determine an airport's landside capacity. Simulation is a simpler technique because it mimics the actions of every passengers and the landside processes that they need to go through without the need to develop any analytical models. Simulation requires input parameters for the model to be accurate. However, many organizations do not have a systematic way to archive data that is necessary for simulation (Sprague and Carlson, 1982). A DSS is made up of the data management sub-system, model management sub-system and user interface sub-system (Turban, 2005). The data management sub-system will overcome this problem (Turban, 2005).

This following had been accomplished through this study:

- A framework for a Decision Support System (DSS) for airport landside capacity planning had been developed. This framework consist of the

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components that made up a DSS for airport landside capacity planning and steps for the development of a DSS for airport landside capacity planning.

- A simulation model for the model management sub-system had been developed by using Singapore Changi Airport Terminal 2 as a case study.

- The capabilities of the simulation model had been demonstrated by performing scenario analysis.

The key results and contributions achieved through this study are systematic steps for DSS developers to follow when developing a DSS for the domain of airport landside capacity planning and a simulation model of Singapore Changi Airport Termnal 2 which DSS developers can use as a template for modeling another airport.

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ACKNOWLEDGEMENT

I would like to extend my heartfelt gratitude to several people without whom this study would not have been possible.

I would like to thank my supervisors Dr. Roger Jiao, Dr. Arun Kumar and Dr Chen Songlin for their guidance and encouragement. A big thank you to various people from the airport community. They are Mr Desmond Chong (Head of Operations, Terminal 2, Civil Aviation Authority of Singapore) who explained to me the passenger processes, Ms Chua (Manager, DFS Galleria) who had given me insights on passengers shopping patterns as well as Ms Zhuang Hanqi (Engineer, Airport Planning) who provided me with the input parameters for simulation as well as her many batches of interns who spent hours on the ground with a stop watch and counter to collect these data. I also wish to thank Mr Tua Phuat Siong (Senior Manager, Changi Airport International) who share with me his experiences in working with airport operators from overseas; and Mr Koh Ming Sue (Deputy Director, Engineering & Real Estate Division) who gave his consent for me to use Changi Airport Terminal 2 as a case study.

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CONTENTS

ABSTRACT **i**

ACKNOWLEDGEMENT **iii**

CONTENTS **iv**

APPENDIX **ix**

LIST OF FIGURES **ix**

LIST OF TABLE **xi**

1 CHAPTER 1: INTRODUCTION **1**

1.1 Airport Planning 1

1.1.1 Categories of Airport Planning 1

1.1.2 Airport Landside Master Planning Process 3

1.1.3 Performance Measure of an Airport's Landside 3

1.2 Trends in the Air Transport Industry 4

1.2.1 Private Sector Participation at Airports 4

1.2.2 Airline Industry Deregulation 6

1.2.3 Formation of Airline Alliance 7

1.2.4 Unstable Geo-political Situation 8

1.2.5 Prevalence of Information and Communication Technology 9

1.3 Challenges Faced by the Airport 10

1.3.1 Managing Volatility in Passenger Traffic 11

1.3.2 Bottom Line Driven 12

1.3.3 Meeting the Needs of Different Airlines 13

1.3.4 Meeting Changing Security Requirements 15

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1.4 Problem Statement & Research Issues 16

1.5 Objective & Scope of Study 16

1.6 Organisation of this Report 17

2 CHAPTER 2: LITERATURE REVIEW 20

2.1 Empirical Methods 20

2.1.1 Rule-of-Thumb 21

2.1.2 Level of Service Criteria 22

2.1.3 Demand Aggregation 25

2.2 Operations Research Methods 27

2.2.1 Queuing Theory 28

2.2.2 Mathematical Programming 31

2.2.3 Data Envelopment Analysis (DEA) 35

2.2.4 Simulation Modeling 38

2.3 Decision Support System 42

2.3.1 Decision Support System versus Management Information System 42

2.3.2 Decision Support System for Airport Planning 44

2.4 Research Gap 46

3 CHAPTER 3: DECISION SUPPORT SYSTEM FRAMEWORK FOR AIRPORT LANDSIDE CAPACITY PLANNING 49

3.1 Rationale for Using Simulation Based Decision Support System 49

3.2 Application Case- Singapore Changi Airport Terminal 2 50

3.3 Components of a Decision Support System for Airport Landside Capacity Planning 51

ATTENTION: The Singapore Copyright Act applies to the use of this document. Nanyang Technological University Library

3.3.1 Data Management Sub-system 51

3.3.2 Model Management Sub-system 52

3.3.3 User Interface Sub-system 53

3.4 Steps for Developing a DSS for Airport Landside Capacity Planning 54

3.4.1 Understand Airport Operations 57

3.4.2 Set Airport Design Objective and Performance Indicators 60

3.4.3 Preliminaries 61

3.4.4 System Analysis 62

3.4.5 System Design 64

3.4.6 Prototype Implementation 67

3.4.7 Operation 68

3.4.8 Modification 69

4 CHAPTER 4: SIMULATION MODEL DEVELOPMENT 70

4.1 Modeling Originating Passengers 70

4.1.1 Import Departure Flight Schedule and Passengers Attribute 71

4.1.2 Modeling Passenger Split for Different Ground Access Modes 72

4.1.3 Modeling Activities at the Curb 73

4.1.4 Modeling Group Check-in Operations 75

4.1.5 Modeling Passenger's Choice of Check-in Row 76

4.1.6 Modeling Check-in Operations 78

4.1.7 Modeling Immigration Operations 79

4.1.8 Modeling Originating Passengers Activities in the Departure/ Transit Hall 80

4.1.9 Modeling Passenger's Walking Speed 87

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	4.1.10 Modeling Operations in the Gate Lounge	88
4.2	Modeling Transfer and Terminating Passengers	99
	4.2.1 Import Arrival Flight Schedule and Passengers Attribute	99
	4.2.2 Modeling Terminating and Transfer Passengers Deplaning	102
	4.2.3 Modeling Transfer Passengers Activities in the Departure/Transit Hall	104
4.3	Modeling Well-Wishers	105
	4.3.1 Import Well-Wisher's Attribute	105
	4.3.2 Modeling Well-Wisher's Split for Different Ground Access Modes	106
	4.3.3 Modeling Well-Wishers' Activities in the Check-in Hall	107
	4.3.4 Modeling Well-Wisher Leaving the Airport	109
4.4	Model Verification and Validation	110
5	**CHAPTER 5: SIMULATION EXPERIMENT & RESULTS**	**111**
5.1	Scenario Analysis: Scenario 1- Peak Hour Analysis	111
	5.1.1 Design of Experiment	111
	5.1.2 Input Data	112
	5.1.3 Simulation Run and Results	117
5.2	Scenario Analysis: Scenario 2- Operation of Airbus A380 on High Density Routes	119
	5.2.1 Design of Experiment	119
	5.2.2 Input Data	120
	5.2.3 Simulation Run and Results	120
5.3	Sensitivity Analysis: Passenger Arrival Profile	123

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5.3.1 Design of Experiment 124

5.3.2 Input Data 124

5.3.3 Simulation Run and Results 125

6 CHAPTER 6: CONCLUSION & FUTURE WORK 128

6.1 Conclusion 128

6.2 Future Work 129

REFERENCES 132

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APPENDIX

Appendix A	Interview Structure & Notes
Appendix B	Data Stored in the Database Management Sub-System
Appendix C	ARENA Simulation Model User Guide
Appendix D	ARENA's User Interface
Appendix E	Commonly used ARENA Modules
Appendix F	ARENA model for Changi Airport Terminal 2
Appendix G	Animation of simulation model
Appendix H	Space to be provided for passengers in different functions

LIST OF FIGURES

Figure 1.1	Organisation of this report	19
Figure 2.1	Cumulative demand for a processing facility	26
Figure 2.2	Efficient frontiers of a DMU	36
Figure 2.3	Steps for conducting simulation studies	41
Figure 2.4	Schematic of a generic DSS	43
Figure 2.5	System architecture of OPAL Decision Support System	45
Figure 3.1	Layout of Singapore Changi Airport's Terminal 2	51
Figure 3.2	Schematic of the model management sub-system for Changi Airport Terminal 2 landside capacity planning DSS	53
Figure 3.3	Schematic of the user interface sub-system for Changi Airport Terminal 2 landside capacity planning DSS	54
Figure 3.4	Steps in the development of DSS for airport landside capacity planning	56

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Figure 3.5	Flowchart depicting passengers flow in Changi Airport Terminal 2	66
Figure 4.1	Importing flight schedule and passengers attribute	72
Figure 4.2	Modeling passenger split between different ground access modes	73
Figure 4.3	Modeling vehicle arrivals at the curb	74
Figure 4.4	Modeling process at the curb	74
Figure 4.5	Modeling group check-in	75
Figure 4.6	Modeling passengers choice of check-in row	77
Figure 4.7	Modeling operations at the check-in counter	78
Figure 4.8	Modeling operations at the immigration counters	80
Figure 4.9	Determine dwell time of passengers in departure/ transit hall	82
Figure 4.10	Modeling passenger's activity profile	83
Figure 4.11	Animation of passengers in the departure/ transit hall	85
Figure 4.12	Modeling passengers usage of the rest areas	86
Figure 4.13	Overview of departure/transit hall (north)	87
Figure 4.14	Modeling passengers walking speed	88
Figure 4.15	Animation of a typical gate lounge	90
Figure 4.16	Simulating gate lounge opening time and passengers boarding time using a control entity	92
Figure 4.17	Separating cabin bags and passengers in the gate lounge	94
Figure 4.18	Cabin bags x-ray and metal detector	95
Figure 4.19	Matching cabin bags to passengers	96
Figure 4.20	Modeling operations at the gate editing counter	96
Figure 4.21	Modeling priority boarding of passengers	98

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Figure 4.22	Importing arrival flight schedule and passengers attribute	101
Figure 4.23	Modeling terminating and transfer passengers deplaning	103
Figure 4.24	Identifying terminating and transfer passengers	104
Figure 4.25	Importing well-wishers' attributes	106
Figure 4.26	Modeling well-wisher's split between different modes of ground access	107
Figure 4.27	Modeling well-wishers in the check-in hall	107
Figure 4.28	Animation of dwell space in the check-in hall	108
Figure 4.29	Modeling well wishers at the dwell space near the police check-point and leaving the airport	109
Figure 5.1	ARENA screen shot of simulation results (Counter)	117
Figure 5.2	ARENA screen shot of simulation results (Queue)	118
Figure 5.3	Flight Schedule operating with Airbus A380 aircraft	120

LIST OF TABLE

Table 5.1	Passenger arrival profile	114
Table 5.2	Passengers activity profile	116
Table 5.3	Summary of simulation results	118
Table 5.4	Comparison of results with operating Airbus A380	121
Table 5.5	Comparison between different amount of resources and system performance	123
Table 5.6	Passenger arrival profile in 10 minutes resolution	126
Table 5.7	Comparison of results with different passenger arrival profile	127

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CHAPTER 1

INTRODUCTION

This chapter starts with an overview of airport planning, and is followed by a detailed explanation on the trends and challenges facing the air transport industry and how these have made airport planning become a complex task.

1.1 Airport Planning

This section provides an introduction to airport planning and identifies the sub-set of airport planning (i.e. airport master planning) which this study will focus on. This is followed by a brief description on the process of airport master planning and performance measure of airport landside.

1.1.1 Categories of Airport Planning

Airport planning can be divided into 3 levels (de Neufville and Odoni, 2003). They are airport system plan, which is a representation of the aviation facilities required to meet the immediate and future needs of a metropolitan area, region or country; airport master plan which is used to provide guidelines leading to the ultimate development of a specific airport and airport project plan which focused on specific elements of the airport master plan that will be implemented in the near future (Horonjeff and McKelvey, 1994); (Wells and Young, 2004).

An airport can be physically divided into 3 parts. They are the airside, the landside and the environment surrounding the airport (Wells and Young, 2004). The airside of an airport refers to the area of an airport where the aircraft uses, for

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example the runway, taxiway and apron. Examples of issues concerning the airside will be pavement engineering; Communications, Navigation, Surveillance, Air Traffic Management (CNS/ATM); runway and airspace capacity.

The landside of an airport refers to the area of the airport that is used by passengers and members of the public, for example the departure and arrival hall, waiting lounge, customs, immigration and quarantine (CIQ) area. The issues concerning the landside will be passenger building configuration, Level of Service (LOS) which is determined by the congestion level in an airport terminal and capacity of passenger processing resources such as check-in positions.

The issues concerning the environment surrounding an airport includes land use planning, for example the availability of land for expanding both the landside and airside capacity and the development of land adjacent to an airport for other uses such as fuel farm, hotel, aircraft maintenance hanger and parking garage (Wells and Young, 2004). It also deals with the environmental effects of airport construction and operations, for example noise pollution caused by aircraft landing and taking off from an airport and the carbon footprint of an airport.

The focus of this study is on landside capacity planning. Landside capacity refers to the capability of the airport's landside facilities and services to process and accommodate passengers. (Transportation Research Board, 1987)

1.1.2 Airport Landside Master Planning Process

Horonjeff (1994) and Ashford (1992) have proposed the steps to be taken to carry out airport landside capacity planning. The first step of an airport landside master planning process is to inventory existing airport facilities, current passenger traffic

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and issues related to the landside capacity of the airport. Next, a forecast of passenger traffic is carried out. The forecast is divided into short, medium and long term forecasts which estimate the number of passengers using the airport for the next 2 to 4, 5 to 10 and 10 to 15 years respectively. This is followed by an analysis of the current capacity of the airport that will identify the gap between current capacity and future demand. Lastly, future demand is translated into facility requirement using empirical formulas, analytical methods or simulation modeling.

1.1.3 Performance Measure of an Airport's Landside

There must be sufficient facilities for handling passengers and visitors in an airport. An assessment of the effectiveness of an airport to handle passengers is measured by (FAA, 1988) :

- queue length at passenger processing facilities
- waiting time of passengers at passenger processing facilities
- congestion level of flow corridors
- congestion level in passengers circulation space.

1.2 Trends in the Air Transport Industry

This section outlines the trends in the air transport industry. Some of these trends affect airports directly while others have a direct impact on airlines. As airports are planned and developed based on the needs of airlines, trends that have a direct impact on airlines will also have an indirect impact on airports hence these trends cannot be ignored by airport planners.

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1.2.1 Private Sector Participation at Airports

Privatization of airports refers to shifting certain governmental functions and responsibilities to the private sector (Wells and Young, 2004). This involves the transfer of rights to residual income arising from airport operations and management control of the airport from the government to a private entity (de Neufville and Odoni, 2003). Privatization can be carried out in different ways. The common vehicles are full privatization or partial divestiture, concession or build-operate-transfer (BOT) contract and management contract (Asian Development Bank, 2000).

A full privatization of an airport is implemented through flotation or trade sales. The private sector entity is responsible for the ownership, investment, management and operation of the airport infrastructure. A partial divestiture is similar to a full privatization except that the government still maintains share holdings in the airport company. The private entity acts as a partner in a joint venture to provide extra investment capital or as a strategic partner to increase the efficiency of existing operations. For example, a portion of the shares of Vienna Airport is privately held (Asian Development Bank, 2000).

Under a concession or build-operate-transfer (BOT) contract, a private entity finances, builds or modernizes a facility and operates it for a certain period of years after which the ownership is transferred to the state. The private entity has the right to the revenue of the airport during the period which it operated the airport. An example is a new terminal at Ataturk International Airport in Turkey whereby the Turkish government implemented a BOT contract of 3 years 9 months (Asian Development Bank, 2000).

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Under a management contract, the ownership and investment of the airport is maintained by the state, and management and operation is carried out through a private entity. The private entity is paid to operate the airport and it must meet the service level set in the contract for example, level of service, availability of mission critical systems such as baggage handling system, and aircraft contact stands or faces a penalty.

The immediate advantage of privatization is the large proceeds from the exercise. In 2004, Hong Kong officials have considered selling 25% of the airport's stock in a bid to raise US$1 billion or more to offset deficit accumulated by the city (Business Week, 2004).

It is also commonly perceived that a private enterprise can operate an airport more efficiently and cost effectively. When BAA was sold to a consortium led by Spanish infrastructure development company Ferrovial in 2006, Chief Executive Officer Nigel Turner of British Midland- UK second largest airline said that he would expect to see a reduction in airport user charges as Ferrovial could bring about operational efficiencies (Airport Business, 2006).

1.2.2 Airline Industry Deregulation

The United States of America began to deregulate the airline industry in 1978. The deregulation did away with governmental restriction on airline destinations, frequency of service, fares and aircraft capacity. This means that an airline in the United States can increase or decrease it's passenger volume to suit market conditions without the need for government approval (de Neufville and Odoni, 2003). The EU followed suit although it only completed its deregulation in year 2000. Many government in Asia

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have also come to realize the benefits of a deregulated air space for the country's economy (Times of India, 2005). These government began to exchange bilateral air services agreements with other countries and this trend is expected to continue.

There are nine different levels of air service agreements, which is known as the Freedom of the Air (ICAO). Most countries have exchanged the first four Freedom of the Air in bilateral or multi-lateral air services agreement. The first four Freedom of the Air grants the airline of a country the privilege to fly across it, land in its territory for non-revenue purpose for example, refueling and to have schedule revenue air services to and from the two countries with passenger enplaning and deplaning from both countries. These four Freedom Rights are normally exchanged whenever two countries have diplomatic ties, and have negligible impact on the air transport industry. However, the Fifth Freedom of Rights has a major impact to the aviation industry.

The Fifth Freedom Rights is the privilege granted by one State (i.e. country) to another State to put down or to take on, in the territory of the first State, traffic coming from or destined to a third State. This is the right granted to take on passenger at a foreign country and deplane them in another foreign country as part of a continuous operation that serves the airline's home country. For example, Singapore Airlines exercises its Fifth Freedom Rights for flights from Singapore to Los Angeles by stopping in Taipei to enplane or deplane passengers. As illustrated above, this Right subjected the Taipei-Los Angeles market segment in Taipei to competition by Singapore Airlines as consumers in Taipei have a choice to fly another airline other than those that are based in Taiwan or the United States. This trend of granting the Fifth Freedom of the Air will continue as airlines seek to expand their

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route and countries start to realise the benefits of such air rights on their economy and to the consumers.

1.2.3 Formation of Airline Alliance

During the infancy of commercial air travel, an airline is often an icon of the country that they are based and they proudly present their national identity through the aircraft's livery and the uniform of the cabin crew. However, the industry trend is towards the formation of airline alliance in order to capitalize on each other's route network and reduce operating cost through the sharing of facilities. According to the IATA 2005 Annual Report, the three largest airline alliance in the world- Star Alliance, One World and Sky Team has a total of 38 member airlines and carried 58% of the world's passenger traffic.

Airline alliance capitalises on each other's network through code sharing agreements. Code sharing refers to the practice of one airline selling seats on a flight that is operated by another airline but advertises the flight as its own. This enables the alliance to offer more frequent flights and to reduce lay over time for passenger by co-ordinating the arrival and departure schedule of their flights.

In the face of competition from low cost carriers and high oil prices, it becomes essential for airlines to control their operating cost. To do so, airline alliance frequently shares some ground facilities such as check in counters, self check in kiosk and Commercially Important Passenger (CIP) lounge. When this is done the brand and identity of each airline is no longer as distinct as it used to be and airlines are increasingly marketing themselves as members of an alliance.

1.2.4 Unstable Geo-political Situation

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Unstable geo-political situation around the world has sent shock waves across the aviation industry that is struggling to recover from its losses. From 2000 to 2003, the world's scheduled airlines posted a combined operating deficit of US$19.5 billion (ICAO, 2003). Every hope for recovery was quickly wiped out by unforeseen events, for example the 9/11 terrorist attacks, the second Gulf War, SARS (Severe Acute Respiratory Symptom) outbreak in 2003- the first time the spread of disease is accentuated by air travel, the Tsunami on Boxing Day 2004 and then the oil prices hike which was due to increased tension in the Middle East.

Airlines have to change their operating model quickly in order to adapt to the increasingly uncertain business environment. The CEO of All Nippon Airways (ANA) said that the industry needs to "move quickly to adjust to crises and challenges" (Aviation Week and Space Technology, 2006). Malaysia Airline's business turn around plan, stated that the "frequency and impact from global demand shocks is increasing… and (it) need(s) to have the flexibility and agility to react to demand shocks…" (Malaysia Airlines, 2006).

1.2.5 Prevalence of Information and Communication Technology (ICT).

The air transport industry has been embracing technological innovations brought about by the development in ICT. These included e-ticketing, bar coded boarding pass (BCBP), Common Use Self Service (CUSS) kiosk which allows passenger to perform check-in formalities at their convenience and biometrics identification of passengers. IATA started a programme known as Simplifying the Business (StB) to streamline processes in an effort to reduce complexity and cost by leveraging on technology (IATA, 2006). E-ticketing, BCBP and CUSS are three out of the five focus areas of IATA's StB programme. At the early stages of ICT innovation, each

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airline develops their own proprietary applications and maintains their own IT infrastructure. However, competition has led them to focus on their core activities and the industry began to develop a common standard so that IT applications and infrastructure- area which airlines do not compete with each other can be shared (SITA, 2004).

An airport IT trend survey conducted jointly by Airport Council International (ACI), SITA and Airline Business in 2006 showed that 59% of the respondents saw an increase in IT budget and it is evident that ICT applications are well received by the air transport industry (SITA, 2006).

E-ticketing and BCBP give passengers the convenience of printing their air ticket and boarding pass from a home or office printer. An e-ticket holds the information previously held on a paper ticket in the form of an electronic record. This system uses a database that integrates with an airline's passenger service system. A BCBP replaces the current magnetic strip boarding passes and can hold information for multiple flight sectors across different airlines with a single boarding pass. IATA estimated that the industry can save a total of 5.5 billion per annum with e-ticketing and BCBP (IATA, 2006).

CUSS kiosk allows different airlines to share self-service check-in workstations that can be located at the airport or at off-site locations like hotel lobbies, convention centers or railway stations. Self-service kiosk for check-in has been used at airports for many years but these systems were proprietary and each airline developed its own system to target frequent flyers and business travelers. In order to reduce operating cost, airlines have started to adopt a common industry standard so that a CUSS kiosk can be shared by different airlines. Airlines have also extended the notion of sharing

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a CUSS kiosk to include sharing of equipment required to perform check-in and departure formalities. This system known as Common Use Terminal Equipment (CUTE) allows different airlines to use the same workstation in the check-in and departure desk environment. A shared IT infrastructure with a common protocol not only reduces operating cost but also allows for scalability of the system (SITA, 2004).

1.3 Challenges Faced by An Airport

The following are the challenges faced by an airport that arise from the trends in the air transport industry.

1.3.1 Managing Volatility in Passenger Traffic

It is evident from the various trends in the air transport industry that there is an increase in the volatility in passenger traffic of an airport. Trends that caused an increase in volatility are deregulation of the air transport industry and an unstable geo-political environment.

After a country deregulated its air transport industry, an airline can change its hub from one airport to another quickly without the need to go through the lengthy process of obtaining government approval. When this happens, the passenger traffic suddenly decreases in one airport and increases in another. For example, in the mid 1990s US Airways moved a large percentage of its international traffic from Baltimore/ Washington hub to Philadelphia (de Neufville and Odoni, 2003). This is a challenge for airport planners in both airports because they need to take into account the fluctuation in passenger traffic. The airport that sees a sudden reduction in passenger numbers needs to cut back the operations of its existing facilities rapidly to reduce operating cost and whereas the airport that sees a sudden increase in passenger

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numbers needs to implement solutions to cope with the surge and maintain its level of service. Before deregulation, both airports will have time to prepare for this drastic change in passenger traffic because an airline needs time to obtain approval from the government before shifting its hub. However, in today's post-deregulation era, government approval is no longer required and this has shortened the time taken for an airline to change its hub. Consequently, the airport has less time to react to such changes in passenger traffic.

The global geo-political environment has a direct impact on passenger traffic. There was a sharp decline in traffic after events such as the September 11 terror attacks in 2001, the SARS disease in 2003 and the Asia tsunami in 2004. Airport operators are hit doubly hard because they not only face a decrease in both aeronautical and non-aeronautical revenue due to a reduction in passenger numbers and frequency of flight but are also pressured to reduce aeronautical charges and concession rentals in order to help airlines and concession operators tide over the difficult times (Horonjeff and McKelvey, 1994). In order to do so, the airport itself must be able to reduce its own operating cost.

The high frequency of these demand shocks also mean that airport planners have to take into account the impact of similar events in the future and how these events will affect passenger traffic and the demand on airport facilities.

1.3.2 Bottom Line Driven

The trend towards airport privatization means that airports in the future can no longer be operated as a facility that is dependent on support and subsidy from the state, instead it must be commercially viable. Airport operators that are listed on the stock

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exchange are accountable to their share holders for their profit and loss and must operate their airports as efficiently and cost effectively as possible in order to maximize profit. Furthermore, a company that privatized an airport through a Build Operate Transfer (BOT) agreement would normally invest with minimum capital in order to maximize the rate of return and shorten the pay back period. As a result, the passenger terminal is frequently designed to be as small as possible but with flexibility for expansion when traffic grows. According to 1998 figures, the construction cost of airport terminal in Britain is between US$1,600 to US$3,500 per square meters (Building, 1999). Airport planners not only must design airports of the correct capacity to meet their projected passenger traffic but at the same time must be able to expand quickly to harness business opportunities when there is a growth in traffic and to shrink quickly to reduce operating cost when the market turns unfavorable.

If an airport privatization is carried out by means of a management contract, the airport operators must be able to meet the service level spelt out in the agreement or they will be penalised. Examples of service levels are congestion levels in the terminal, waiting time and queue length at passenger processing points such as check-in, immigration and baggage claim. Hence, it is evident that airport planners play a significant role to provide optimal capacity at the lowest capital and operating cost.

1.3.3 Meeting the Needs of Different Airlines

Airports must be able to change their facilities quickly to meet the ever changing needs of airlines in order to attract more airlines to fly to them. Low cost carriers (LCC) have different needs compared to a network carrier. The needs and operations

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of an airline also change when it joins an alliance or adopts a new technology to streamline its process.

In the past, airports have been planned to cater for the needs of network airlines by having sufficient facilities such as aircraft contact stands and check-in counters. However, deregulation has led to a proliferation of LCC and their needs are different from that of network airlines. The objective of an LCC is to minimize operating cost and pass on these savings to its passengers. As such, many LCC do not want to use contact stands or use less number of check-in counters at the expense of lower service standard. It is evident from the above that planning assumptions for a network airline is different from that of a LCC. Airport planners must acknowledge that LCC are growing and they form a significant portion of air traffic at an airport. In Singapore Changi Airport, LCC flights made up 11.3% of the traffic and their unique operating model cannot be ignored (Aviation Week and Space Technology, 2006). As such, airport planners must take into account both the needs of network airline and LCC as their growth or decline in traffic has different impact on the demand for airport resources.

An airline that joins an alliance may require the airport to shift its aircraft contact stands and check-in facilities such that they are close to other members of the alliance in order to gain the benefits such alliance bring about. The airline may even shut down its own CIP lounge and share the use of its alliance partner's lounge. Airport planners need to take into account the possibility of such an event happening in the future.

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The wide acceptance of Information and Communication Technology (ICT) coupled with the various advantages it offers means that e-ticketing, bar coded boarding pass (BCBP) and common use self service (CUSS) kiosk will be increasingly adopted by more and more airlines. Airports must be able to support these IT infrastructure by having sufficient computer network servers rooms, network access points or even wireless network coverage. Airport planners must cater for space in the departure hall for CUSS kiosk while the demand for check-in counters may increase at a slower rate.

1.3.4 Meeting Changing Security Requirements

Terrorist activities showed no sign of abating and government security agency are continuously introducing stricter measures to screen passengers in response to the increased security threats. There have been many instances where security screening procedures have to be changed within hours because of new threats and this has many implications on airline and airport operations.

In 2001, a failed attempt to blow up an aircraft with improvised explosive device (IED) hidden in shoes resulted in a new security procedure whereby passengers had to remove their shoes and put them through an x-ray machine. This resulted in long queues forming at security screening check points and flight delays. In August 2006, a group of terrorists plotted to blow up several aircraft departing from U.K. by combining liquids otherwise harmless by itself to make a bomb after passing through security. Fortunately, the plot was foiled by British security agencies but the new security measures which required passenger manifest to be screened before the aircraft could take off caused flights to be delayed for up to 3 to 4 hours. Temporary shelters were constructed outside Heathrow airport for the delayed passengers as the

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terminal was overcrowded. In an effort to stem the congestion, flight schedules were reduced by 20% for the week and some analysts estimated that British Airways could lose up to 50 million pounds as a result of these cancellations (Aviation Week and Space Technology, 2006). British Airways as well as IATA condemned BAA, the airport operator for not having an adequate plan to respond to such security crisis. BAA which was recently acquired by Ferrovial, a Spanish company became laden with potential damages payment to airlines as well as higher security cost.

The above clearly illustrated that such acts of terror occurred frequently and its impact on airport operations must be taken into consideration in airport planning. It not only affects the service level of the airport operator but also has a financial impact. An airport owned by the government may be able to compensate airlines for delay due to security concerns. However, a privatized airport may not be able to bear hefty compensations without facing financial difficulties.

1.4 Problem Statement & Research Issues

Airport landside capacity planning formulates the amount of resources needed for passenger processing to meet a defined level of passenger traffic. However, it is difficult to forecast passenger traffic accurately due to increased volatility in passenger traffic (de Neufville and Odoni, 2003). Moreover, passenger traffic does not simply translate mathematically into the amount of resources required.

Airport landside capacity planning is normally performed using operations research methods (Ashford, 1992). However, these classical methods are not accurate enough.

1.5 Objective & Scope of Study

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This study shall develop a framework for a simulation based decision support system for airport landside capacity planning. This is a more accurate method. The following are the objectives of this study:

- Develop a framework for a Decision Support System (DSS) for airport landside capacity planning, including the components that make up a DSS and steps for DSS development.

- Develop a simulation model for the model management sub-system of the DSS using Singapore Changi Airport Terminal 2 as an example.

- Demonstrate the capabilities of the simulation model by performing scenario analysis.

1.6 Organisation of this Report

Figure 1.1 is a diagram showing the organization of this report. This report started with the various categories of airport planning and a airport master planning process. The trends and challenges facing the air transport industry and how these made airport landside capacity planning a complex task were also discussed.

The next chapter will review the various methods used in airport landside capacity planning and Decision Support System (DSS). This is followed by Chapter 3 which will identify simulation based decision support as a suitable method for this study and present the reasons for choosing this method. It also present the components that made up a DSS and the steps for developing a DSS for airport landside capacity planning.

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The focus of Chapter 4 is on simulation model development. It presents detail on how ARENA was used to model the processes of originating and transfer passengers as well as well-wishers. This is followed by Chapter 5 which uses the model developed in the preceding chapter to conduct scenario analysis and sensitivity analysis. The final chapter concludes this report and suggests future work for this study.

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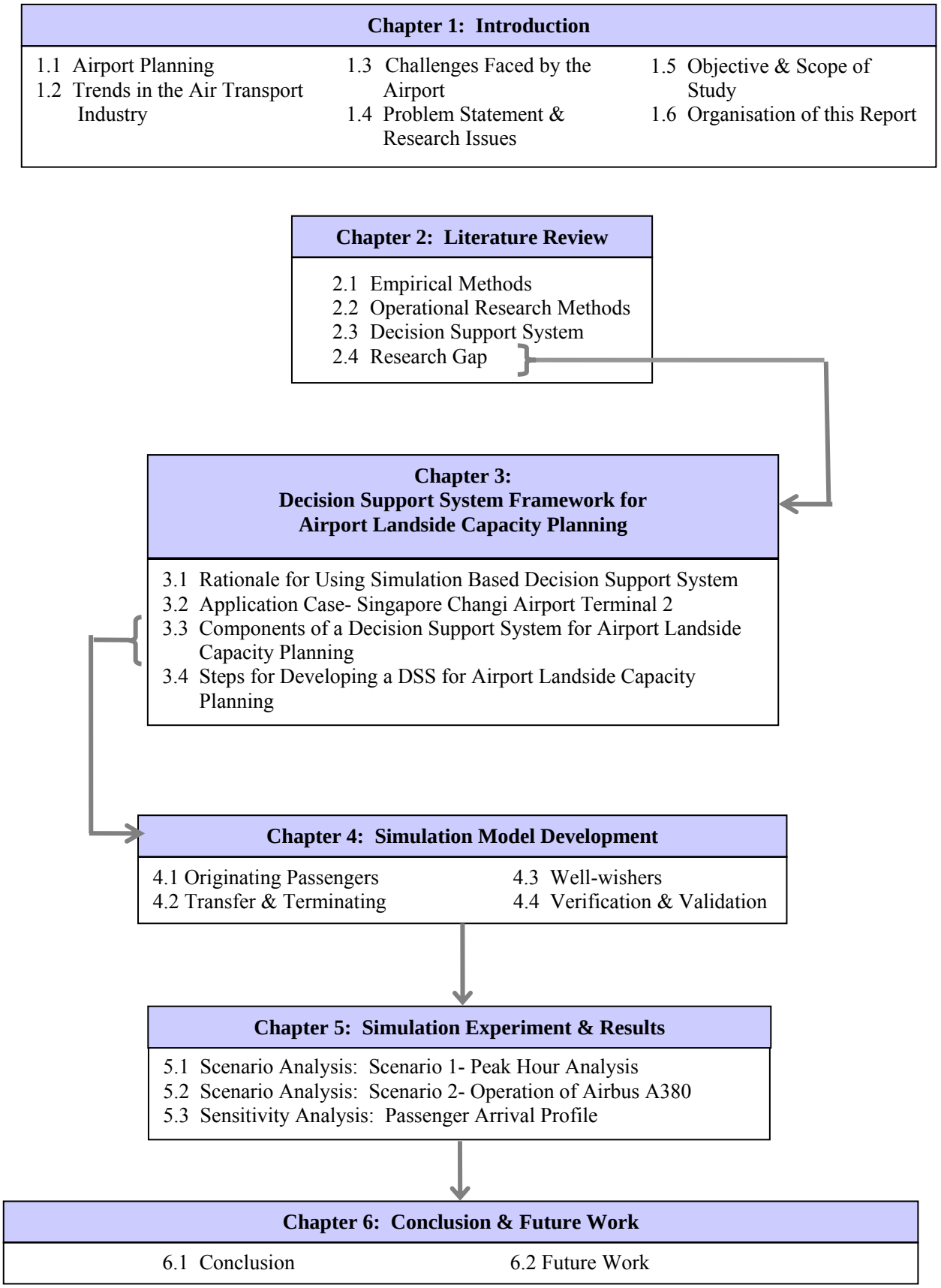

Figure 1.1: Organisation of this report

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CHAPTER 2

LITERATURE REVIEW

Empirical methods used in airport landside capacity planning would be reviewed in the first section. In the second section, operations research methods would be reviewed. The next section would review literature on Decision Support System and the last section discuss research gaps.

2.1 Empirical Methods

In 1987, the FAA expected the annual number of passengers using the airport in the United States to grow more than 70 percent in 10 years time. A committee was convened to recommend rule-of-thumbs in assessing the capacity of critical landside components such as passenger waiting area, curb, car parking space and security screening. These are developed based on the typical demand patterns that the component must accommodate.

The International Air Transport Association (IATA) also developed a similar set of formulae. In addition, IATA uses the Level of Service criteria which has both qualitative and quantitative criteria to describe the level of congestion in airport terminals. The rationale behind this is that level of congestion is inversely proportional to airport landside capacity.

Other researchers aggregate the demand for landside components from different flights to determine the total demand for landside components. The number of landside components needed is then determined from the processing rate of each component.

2.1.1 Rule-of-Thumb

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Rule-of-thumbs translate passenger arrival rate and processing time into the number of resources needed using simple formula, table or graph. It is often developed based on the accumulated experience and industry best practices of airport planning practitioners. FAA and IATA published manuals that consist of these rule-of-thumbs. These could be found in the Airport Development Reference Manual published by IATA (2004) or the Advisory Circular on Planning and Design Guidelines for Airport Terminal Facilities published by the FAA (1988) in the United States.

The following example is used to illustrate the use of a rule-of-thumb that determine the number of baggage claim carousels. This has been extracted from IATA's ADRM. IATA recommended that the length of a baggage claim carousel for a wide body aircraft should be between 70m to 90m while that for a narrow body aircraft should be between 40m to 70m.

$$BC_{\text{wide body}} = \frac{PHP \text{ x } PWB \text{ x } CDW}{60 \text{ x } NWB}$$

$$BC_{\text{narrow body}} = \frac{PHP \text{ x } PNB \text{ x } CDN}{60 \text{ x } NNB}$$

where BC = number of baggage claim carousels needed,

PHP = peak hour number of terminating passengers,

PWB = proportion of passengers arriving by wide body aircraft,

PNB = proportion of passengers arriving by narrow body aircraft,

CDW= average claim device occupancy time per wide body aircraft,

CDN = average claim device occupancy time per narrow body aircraft,

NWB = no. of passengers per wide body aircraft at 80% load factor, and

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NNB = no. of passengers per narrow body aircraft at 80% load factor.

The above example showed that this rule-of-thumb assumed that passenger arrived at the baggage claim hall at a constant rate and did not take into account possible operational aspects such as sharing of carousels with other arrival flights. This method is deterministic as it assumed that input parameters like CDW or CDN, the average claim device occupancy are constants and not probabilistic quantities.

Although this method is an over simplification of the actual operations at an airport, it is still used as a "first cut" analysis because it is fast and easy to apply (de Neufville and Odoni, 2003).

2.1.2 Level of Service Criteria

Another method to determine the quantity of resources needed for passenger processing is to use the level of service criteria as a yard stick. Airport landside capacity is a measure of the throughput of the airport terminal but a relationship must be established between the capacity of an airport terminal and the level of service provided to passengers because an airport is capable of operating at various degrees of congestion and waiting time for passengers. Hence, it is important to relate the capacity of an airport to the level of service.

Most of the assessments on service levels are qualitative in nature. Passengers will be asked to assess the quality of service based on attributes such as speed of check-in; lounges and waiting areas; customs and immigration; food and beverage; and shopping (ACCA/IATA, 1981).

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IATA (2004) quantify level of service by establishing a criteria that allows for comparison between different passenger processing facility. The association defined the level of service as a range of values indicating how well an airport's facility can meet its demand. Level of service A corresponds to " an excellent level of service. Conditions of (people) free flow (in the terminal), no delays (at passenger processing points) and excellent levels of comfort" while level of service F means "unacceptable level of service. Conditions of (people) cross-flows (in the terminal), system breakdowns and unacceptable delays and unacceptable level of comfort".

IATA has also developed a set of space standards for various passenger processing facility such as check-in hall, passport control and baggage claim hall. This set of standard prescribes the minimum area a passenger is given for the various level of service. In order for an airport to improve its level of service, it must either allow for more space at these facilities or to increase the number of servers in order to process passengers quickly thus reduce the percentage of occupancy at these facility. For example, the space standard for level of service A, B, C, D, E at passport control is 1.4 m^2, 1.2 m^2, 1.0 m^2, 0.8 m^2 and 0.6 m^2 respectively.

In most cases of analysis and planning of airport landside capacity, space and waiting time standards have been considered independent of each other. Janic (2003) combines IATA's concept of space standard with the widely used service standard of waiting time by using indifference curves to explain the dependability of both space and time attribute. In doing so, level of service can be expressed in both temporal and spatial attributes. Janic (2003) used queuing theory to determine the 'load' of a particular area of an airport terminal in terms of the number of occupants simultaneously being there.

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He then continued to develop two criteria known as the 'indicator of service quality' (ISQ) and 'space load ratio' (SLR).

The ISQ is intended to bring together both spatial and temporal attributes of the quality of service and can be defined as the ratio between the cumulative passenger delay carried out in a given area and the total size of that area. A general expression for determining ISQ can be formulated as follows (Janic, 2003):

$$ISQ = W(S)/S$$

where $W(S)$ is the cumulative passenger delay carried out in the area of size S in terms of number of passengers per unit area and S is the area of the facility. The above equation expressed the average 'load' per unit area of a particular facility in terms of passenger time units.

The SLR is a ratio between the actual and planned ISQ. An SLR of between 0 and 1 indicates that the load of the area will allow passengers to enjoy a higher quality of service than has been planned. An SLR of 1 indicates that passengers will get exactly the same quality of service as has been planned while an SLR greater than 1 indicates that the load of the area has increased to the level at which the facility can no longer meet the level of service criteria.

Janic (2003) illustrated this method by applying it to a check-in hall, waiting lounge and passageways.

2.1.3 Demand Aggregation

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Park and Ahn (2003) aggregated passengers arrival at the airport to calculate the demand for check-in counters and the duration which check-in counters need to be operated. Inputs of the model are passengers arrival pattern at the airport which shows a distribution of passengers arrival at the airport prior to the scheduled time of departure against time; flight information such as whether it is a domestic or international flight; and processing characteristic such as service time, length of queue and number of check-in bags. A survey was conducted at Seoul Gimpo International Airport to find out the passenger arrival distribution for each flight and an equation of the cumulative distribution is established. The distribution of the individual flight is aggregated in 10 minutes interval to form the demand for check-in counters over a period.

Brunetta *et al* (1999, 2007) used the deterministic equivalent approximation approach to develop a graphical model known as SLAM (Simple Landside Aggregate Model) which computes the total waiting time and queue length at a passenger processing facility. It is an analytical aggregate model for estimating capacity and delays. Their objective is not to provide a thorough analysis of an airport but to provide a quick and simple method to evaluate the service level of an airport from an aggregate point of view. Brunetta *et al* (1999, 2007) did not use classic queuing theory because of the unrealistic assumptions that both the average number of arriving passenger at the processing facility and the average potential service volume of the same facility are approximately constant over a significant period of time. The deterministic equivalent approximation approach will take into account the dynamic effects of variations in the average number of arriving passenger or average potential service volume by following its evolution over time. It will yield a graphical model that computes

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approximately the total waiting time of passengers, given the cumulative arrival function at the processing facility and the service rate for each time period. Figure 2.1 illustrates the concept of this method.

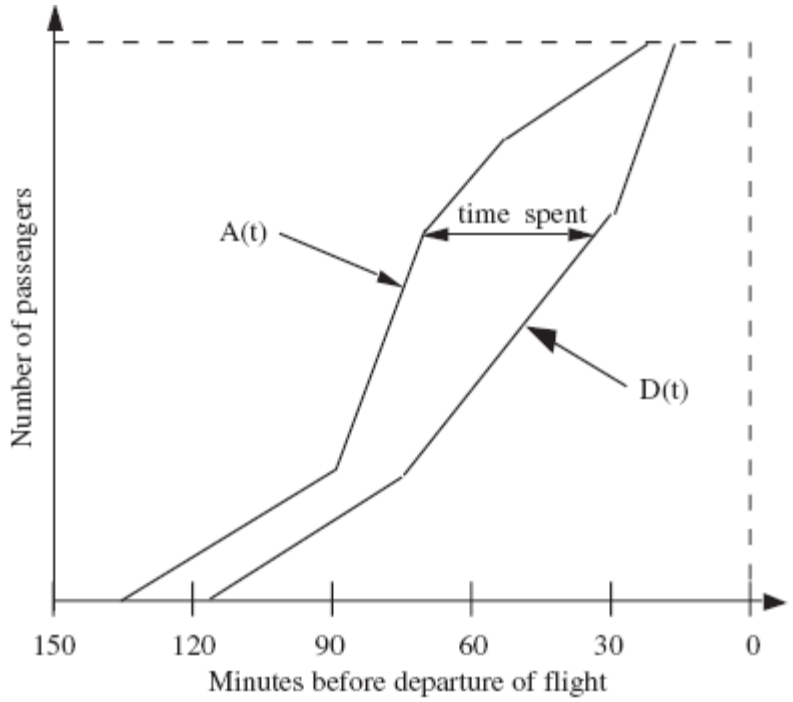

Figure 2.1: Cumulative demand for a processing facility (Brunetta *et al*, 1999)

The cumulative number of passengers that have arrived at the processing facility as a function of time is represented by *A(t)* and the cumulative number of passengers that have been served and have departed from the processing facility is represented by *D(t)*. The later could be inferred from the number of service staff and the mean service time. The difference between the two parameters *A(t)* and *D(t)* will be the number of passengers that are waiting in queue. The waiting time in queue of a passenger is the difference between the inverse of the two functions i.e. $A^{-1}(t) - D^{-1}(t)$.

With the waiting time of the passengers in queue, Brunetta *et al* (1999, 2007) introduced the 'Index of Service' (IOS). The concept of IOS is identical to the concept

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of the 'Indicator of Service Quality' (ISQ) developed by Janic (2003). It attempts to find a relationship between IATA's space standard and the time in which passengers spend at the facility. IOS is given by the area of that facility divided by the product of the average number per hour of arriving passengers at that facility during the time interval under consideration, multiplied by the average waiting time in queue of a passenger in the facility.

Brunetta *et al* (1999, 2007) used JAVA and ANSI C to programme SLAM's user interface and for numerical calculations respectively.

2.2 Operations Research Methods

Airport landside capacity planning can be generalised as an operations research problem in a service system. Different operations research methods have different underlying assumptions, complexity and level of precision. They will yield either deterministic or stochastic results and model the operations of an airport as either a static or dynamic system. A system is static when the state of the system does not vary with time whereas the state of a dynamic system is different at different point in time during the period which the system is under study. A deterministic model has a constant input parameter thus its solution will always be the same for the same set of input parameters. In contrast, a stochastic model takes into account the randomness in input parameters such as processing time and inter-arrival rates (Kelton and Averill, 1982).

This section reviews the various operations research methods used in airport landside capacity planning.

2.2.1 Queuing Theory

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Queuing theory involves the mathematical study of queues and provides a large number of mathematical models for describing a waiting line problem (Gross and Harris, 1998). This method treats passenger processing facilities in the airport as single-channel or multi-channel service facilities modeled by queuing theory. Passengers arrive at a rate that is described by a probability distribution and are served with a service time that is described by another probability distribution. This analytic approach gives output of expected queue length, L and expected waiting time in queue, W for a given number of servers.

Passengers arrive at the airport for different flights typically between 3 hours to 30 minutes before the scheduled departure time. As such, during the peak hour, the arrival of passenger for any flight can be treated as a random process thus it is a Poisson distribution (Hillier and Lieberman, 1998). A Poisson arrival distribution implies an exponential inter-arrival time. In most passenger processes, the service time is often brief but can occasionally be extensive. As such, an exponential service time distribution is a good approximation. This is a M/M/s queuing model, where the first M denotes an exponential (Markovian) inter-arrival time, the second M denotes an exponential service time distribution and s denotes the number of parallel service channels in the queuing system.

The following formulas derived from queuing theory can be used to calculate the expected queue length, $L_{M/M/s}$ and the expected waiting time in queue, $W_{M/M/s}$ for a given number of servers, s in a passenger processing facility:

$$L_{M/M/s} = P_o(\lambda/\mu)^s \rho]/\, s!(1-\rho)^2$$

where λ = mean arrival rate of passenger

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μ = mean service rate of passenger processing facility

s = number of servers

ρ = utilization rate of a group of passenger processing facility serving the same queue

$= \lambda/s\mu$

and

$$P_o = 1 \Big/ \left[\sum_{n=0}^{s-1} \frac{(\lambda/\mu)^n}{n!} + \frac{(\lambda/\mu)^s}{s!} \frac{1}{1-(\lambda/s\mu)} \right]$$

$$W_{M/M/s} = L_{M/M/s}/\lambda$$

McKelvey (1988) recognized that not all passenger processes are of the M/M/s nature. He proposed that the M/M/s model can only be used in situations where the service time is influenced by passenger characteristics, for example at security locations. In processes where a discrete service time was required for passengers such as ticketing, the waiting time in queue should be represented by a M/G/s model, where G denotes a general distribution characterized by its mean and variance. The following formula to determine the average waiting time is used for such processes:

$$W_{M/G/s} = \frac{\nu + \mu^2}{2} \times W_{M/M/s}$$

where ν = the variance of the mean service time

μ = the mean service time

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McKelvey (1988) modelled the airport terminal as a series of passenger processors that are linked together to form a sequenced network through passengers must pass. The processors thesmelves are mathematically represented as queuing mechanism in which a passenger joins a waiting line to enter a processor, enters the processor where service is performed before moving on to the next processor. Each of these processor serves the passenger demand imposed upon it. The links between these processors indicate the possible paths that passengers may take from one processor to another. The percentage of passengers moving to another processor through the particular route and the distance travelled between each component are also indicated on the link. Transition matrixs are used to represent the above information to achieve computation efficiency so that they can be varied without the need to reconstruct the whole network. Finally, the model computes the average passenger delay and service time at each processor in the network and the average travel time between processors. The sum of these three parameters is the average passenger processing time through the airport terminal.

This analytical approach successfully address the level of service criteria by taking into account queue length and expected waiting time and the probabilistic nature of passenger arrival rate as well as service time. These input parameters have taken into account the stochastic nature of airport operations. However, this method failed to deal with the operation's dynamic nature whereby capacity is not constant. For example, ground handling agents will man additional check-in counters when the queue becomes too long.

2.2.2 Mathematical Programming

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Mathematical programming refers to the study of optimization problems in which one seeks to minimize or maximize a function by systematically choosing the values of real variables from within a defined set (McMilan, 1975). The most common application involves allocating limited resources among competing activities in the best possible way. A mathematical programming problem can be represented by an objective function in the form of $f : A \to \mathrm{R}$. A solution for x_0 in A is sought such that $f(x_0) \leq f(x)$ for all x in A in the case where the objective is to find a minimum solution and $f(x_0) \geq f(x)$ for all x in A in the case where the objective is to find a maximum solution. The objective function is specified by a set of constraints which are equalities or inequalities that the members of A have to satisfy.

Solak *et al* (2006) used delay time approximations and multistage stochastic programming for airport terminal capacity planning. Stochastic programming is a sub-set of mathematical programming whereby the constraints are random variables. A decision is made in the first stage, after which a random event occurs. A recourse decision is then made in the subsequent stages to compensate the result of the first stage decision, taking into account the random event. An airport terminal is represented as a network of passenger processes depicted by nodes. Delay functions were developed to approximate delays experienced by passengers at processing stations and the traveling time between these stations i.e. delay in passageway. Solak *et al* (2006) used the relationship between pedestrian's walking speed and density of passageway (passengers/m^3) as suggested by Sarkar et al (1997) and Young (1999) to develop a delay time approximation for walking time as a function of passageway length and width and rate of flow of passenger. They then developed relations to estimate the maximum delay at processing stations as a function of flow and capacity by applying

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queuing theory and assuming various peaking characteristics when demand exceeds capacity, for example parabolic, half-elliptical and triangular.

A multistage stochastic programming technique is then used with the objective of minimising the delay function for passageway and processing stations subjected to capacity constraints. A heuristic was also proposed to solve the objective function.

Dijik and Sluis (2006) used a two step process which consist of simulation and integer linear programming to optimise the number of check-in counter and to assign check-in counter staff while meeting service standard at Amsterdam Schiphol Airport. Integer linear programming is a linear programming model with a constraint that the variables must have integer values. A triple win was achieved in passenger waiting times, staffing hours and number of check-in counters.

In the first step, simulation is used to determine the number of check-in counters required to meet a defined service standard of a maximum allowable queuing time. The simulation was carried out in an iterative manner by increasing the number of check in counters with each simulation run until the service standard is met. In the second step, integer programming is used to determine the minimum staff required and an optimal shift schedule. Dijik and Sluis (2006) proposed two models. A model where each flight will be assigned a fixed number of check-in counters for its entire check-in period is known as the constant desk allocation model while a model that can change the number of counters according to demand is known as the variable allocation model. Both models seek to minimise the total desk requirement in terms of opening hours and number of physical desks subject to the constraint that the check-in desk for the same flight should be adjacent and must also be in the same row.

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Most studies on airport landside capacity dealt with the problem of providing optimal capacity of passenger processing facilities from an engineering perspective. Airport privatization and the uncertain financial situation of airlines has led airports to focus on increasing non-aeronautical revenue instead. However, little studies has been carried out on airport finance from an engineering view point as most studies on airport financial management focus on user charges from an econometric perspective. Hsu and Chao (2005) examined the relationship between concession revenue, passenger service level and space allocation for public facilities (i.e. passenger processing facilities) and concession activities using mathematical programming. The study considered issues including space allocation for passenger processing and commercial activities, terminal concession rate-setting and passenger accessibility in terms of their space-time constrains in undertaking consumption activities in the airport. Hsu and Chao (2005) used mathematical programming to construct a model for maximizing concession revenues while maintaining the level of service in terms of providing sufficient space at passenger processing facilities. The result obtained is the optimal sizes and locations for various types of stores in every region of a passenger terminal. This provides a reference for terminal space planning and lease management.

There are two stream of airport concession revenue. One is from the rental of the retail space and the other is from taking a share in the store's revenue (Hsu and Chao, 2005). A larger space and more facilities available for passenger processing can improve the level of service which allow passengers to finish all formalities more efficiently thus allowing them more time for consumption which increases airport concession revenue. On the other hand, a large space for passenger processing will mean a reduced rentable area and this will lead to a reduction in airport concession revenue. A delicate balance

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must be struck between the amount of space allocated for commercial activities and passenger processing facilities. Hsu and Chao (2005) formulated the above problem using mathematical programming by maximizing the total concession revenue of store *k*, where *k* =1,2,3….., z; subject to two constraints. The first constraint requires that the minimum area of type *k* store to be larger than the minimum space required for the basic service functions of this type of store. The second space constraint sets the total allocated commercial space for all *k* types of stores in a section of the airport be less than the largest commercial space available in that section. This second constraint prevents the over allocation of space for commercial activities and allows space to be kept for public facilities as necessary to maintain good service quality.

Hsu and Chao (2005) went on to develop a formula for the total number of passenger who possibly undertake commercial activities at a store. This formula is a function of the dwell time of passengers after completing all departure formalities, the number of stores they have visited and the walking time between one store and the next as well as the traveling time between the store and the departure gate.

Hsu and Chao (2005) applied their model to Terminals 1 and 2 of Chiang Kai-shek International Airport in Taiwan. The result of their study showed that the concession revenue of Terminal 1 is lesser than that of Terminal 2 because congestion in Terminal 1 has caused passengers to have insufficient time for commercial activities. Based on their model, Hsu and Chao (2005) found that commercial revenue for Terminals 1 and 2 is maximized if Terminal 1 operates between 42 to 49% of its design capacity while the remaining traffic relocate to Terminal 2.

2.2.3 Data Envelopment Analysis (DEA)

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DEA is a non-parametric method designed to measure the performance of an organisation generally known as a Decision Making Unit (DMU) (Charnes *et al*, 1994). In the context of landside capacity analysis, the DMU refers to an airport. DEA is a mathematical technique based on linear programming that does not require that the functional form relating inputs to outputs be specified. This method uses linear programming to construct a piecewise linear 'efficient frontier' that envelops the data based on information on inputs and output only. Efficiency measures are then calculated relative to this frontier.

Fernandes and Pacheco (2002) used Data Envelopment Analysis (DEA) to determine the efficiency of airports with respect to the number of passengers processed. They define efficient airports as those with facilities that have a high utilization rate and thus do not have the ability to process more passengers without expansion or deterioration of service standard. They proposed that DEA could be used as a tool to decide when airport expansion is required.

Fernandes and Pacheco (2002) have defined the number of passengers processed as the output. The inputs include several airport resources such as the number of check-in counters, length of curb frontage and the area of the baggage claim. DEA optimizes each observation in order to construct a constant return to scale (CRS) efficient frontier and a variable returns to scale (VRS) efficient frontier on a graph with input as its horizontal axis and output as its vertical axis. The CRS efficient frontier is a straight line passing through the origin indicating that the output produced is proportional to the input while the VRS efficient frontier is a convex curve that indicates decreasing output for each additional unit of input. Airports that are within the VRS efficient frontier are "inefficient" and have excess capacity to meet future demands. Airports that are on the

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VRS frontier need to explore options to achieve constant returns to scale whereas those that are on the CRS efficient frontier has no choice but to expand its capacity.

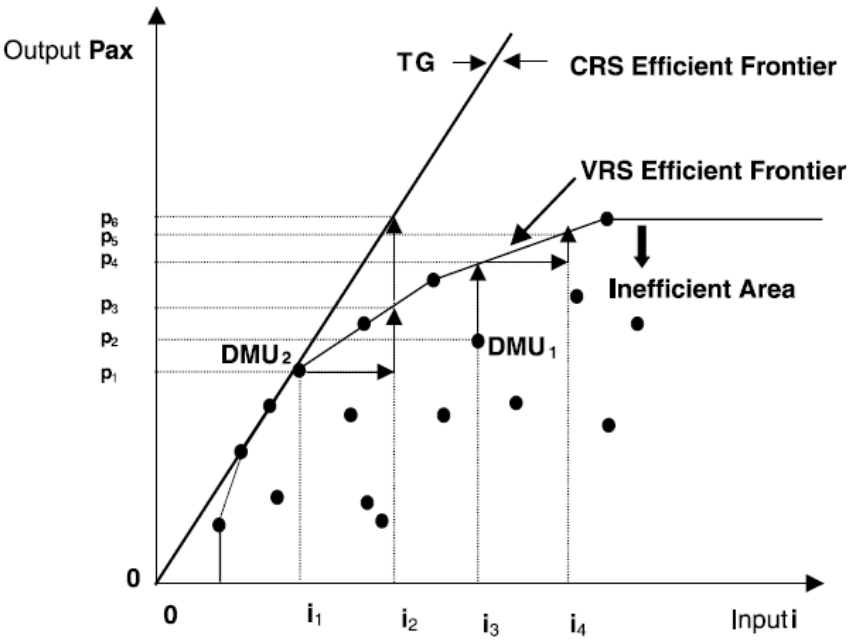

Figure 2.2: Efficient frontiers of a DMU (Fernandes and Pacheco, 2002)

From Figure 2.2, it is seen that DMU_2 which is on the efficient frontier can choose a development route leading to position i_2, p_6. This necessitate a capital investment to expand its facilities in order to increase input i_1 to i_2 and this is considered as a long-term view. On the path to p_6, there is an intersection with the efficient frontier for the VRS at p_3. The output p_3 is at the existing level of technology which is considered a view to a shorter-term horizon. On the other hand, DMU_1 is considered inefficient at output p_2 because the VRS frontier shows that it is possible to produce p_4. For example,

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if input I is the number of baggage claim carousels, the facility at i_3 will be able to operate without change up to the number of passengers p_4. However, expansion would be necessary to attain a higher output to expand the facility to i_4 so as to attain output p_5.

Fernandes and Pacheco (2002) used DEA on 35 domestic airports in Brazil to identify which of the airport uses their resources efficiently and which offered surplus capacity in these resources.

2.2.4 Simulation Modeling

Computer simulation refers to methods for studying models of real-world systems by numerical evaluation using software designed to imitate a system's operations or characteristics over a period of time (Kelton and Averill, 1982). It allows user to conduct simulation experiments to give him/her a better understanding of the behavior of the system for various sets of 'what-if' scenarios or even a new design. For example, before a new security screening procedure is implemented, airport planners can perform a simulation to determine the impact on the level of service and whether existing security screening resources are sufficient.

This method models passenger processes as a group of processes along a production line. The resources used to process passengers such as staff and check-in counters are similar to operators and machines in a factory and passengers are modeled as semi-finished product. The output of the simulation will yield results such as waiting time of passengers in a queue, length of queue and utilization rate of the resources.

Chang and Hee (1998) used SLAM II (Simulation Language for Alternative Modeling) to develop a generic simulation model for the planning and design of an airport

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passenger terminal. This would allow airport planners to test different design and improvements for existing or new terminal building before embarking on any costly construction. SLAM II is a FORTRAN based simulation language. It uses a network structure comprising of nodes and branches to model elements in a process such as queues, servers and decision points. In the departure model, passengers are modeled as entities flowing from the check-in counters to the aircraft, passing through immigration, concessions, food and beverage outlets and security control. In the arrival model, passengers are modeled as entities flowing from the aircraft to the passenger building, passing through immigration, toilets, baggage claim and customs. Time delay in processing passengers as they flow through the network is represented by a branch. Other information are also included in the branch such as the probability or condition for an entity to take the branch, number of parallel servers if the branch represents a process, and an activity number. Branches are used to separate nodes and each node performs a different function for example, create entities, select a queue and free a resource. This network representation of the system is then transcribed by SLAM II's modeler into equivalent statements model to be input into SLAM II's processor. The output from the model includes queue length and utilization of each resources.

Roanes-Lozano *et al* (2004) used MAPLE to simulate passenger's traffic in the departure hall of Malaga Airport in Spain. The programme simulates in detail all the processes taken by each individual from the time they arrive at the terminal to the time they board the aircraft. These processes included check-in, passport control and security checks. A survey was carried out to establish the airport arrival patterns of passengers. The arrival patterns for different type of flight differs and are classified into regular (i.e. scheduled flights), charter, and others. Each passenger is simulated

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individually and is assigned a list of attributes which includes class of travel, check-in time and flight number. They are assigned the shortest queue at each processing point with a FIFO queue discipline. The simulation clock is updated every minute and a warm up time of 150 minutes is used to take into account early morning flights which check-in has started the previous day. The programme is able to show the detailed queuing time of any passenger in the terminal, numerical data about any queue in the terminal at any time, maximum length of any queue and plots of the evolution of any queue. The software was extended to accept data from SADAMA which is another software used by the Malaga Airport Authority to handle flight data such as flight schedule, gates and check-in counters.

There are also commercial-off-the-shelf (COTS) simulation software to simulate airport landside capacity. For example, ARCTerm by Aviation Research Corporation and PaxSim by Boeing are simulation software which have user friendly interfaces that can be used to simulate passenger process from curbside to the aircraft. Some airport planners use general simulation packages such as ARENA by Rockwell Software and WITNESS by the British Laner Group which gave them more modeling flexibility. The simulation model can be animated to provide a powerful visualisation in 2 dimensional or 3 dimensional graphics which often become a tool for the presentation of the simulation result (Jane Airport Review, 2005)

The following figure outlines the steps that are taken to conduct a simulation study (Oaksott, 1997).

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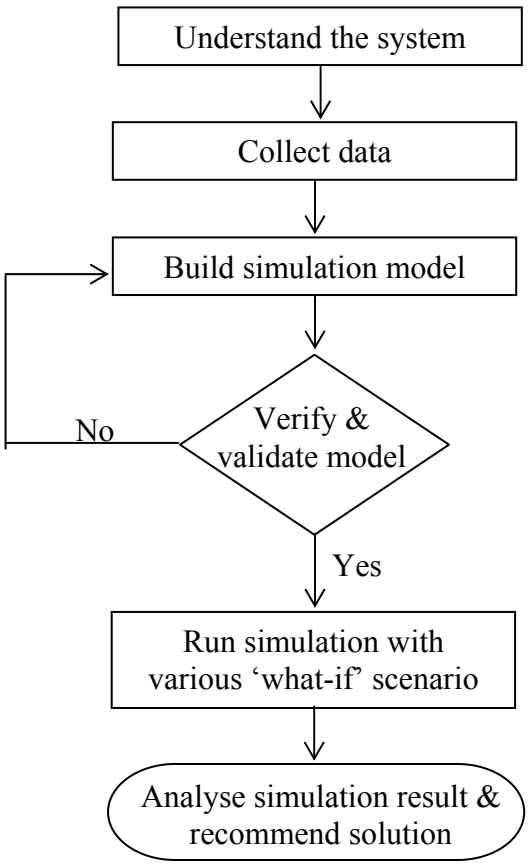

Figure 2.3: Steps for conducting simulation studies (Oaksott, 1997)

Knowledge of the operations of the airport, for example the queue discipline is essential for using simulation as a tool for airport landside capacity planning. Examples of data that need to be collected are the inter-arrival profile of passengers, the shift patterns of the ground handling agents processing check-in, the probability distribution function of the processing time, etc. After the model has been built, the process of verification ensures that the model behaves as intended and there are no bugs in the simulation model. Model validation refers to the task of ensuring that the model behaves in the same way as the actual system would under the same conditions. The next step is to run the simulation with various 'what-if' scenario. The optimal number of resources will be recommended based on the output of the simulation such as waiting time and queue length.

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Since simulation is able to model the stochastic and time-varying characteristic that is inherent to airport landside operations, it is widely regarded as the most accurate tool to determine the landside capacity of an airport.

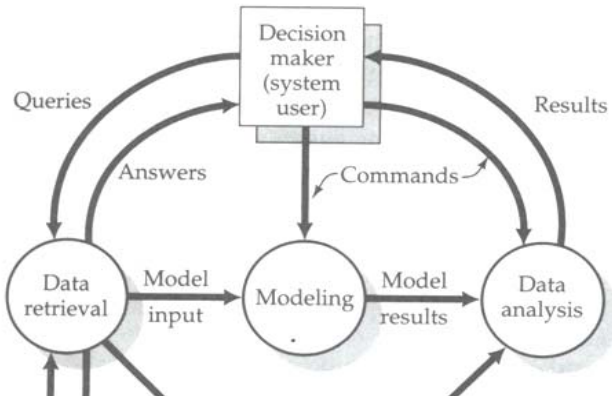
2.3 Decision Support System

A DSS is an interactive, flexible and adaptable computer-based information system, especially developed for supporting the solution of a non-structured management problem for improved decision making (Turban, 2005). They are used to support, not to replace people and are used when the decision is semi-structured or unstructured. DSS incorporates database and models.

This section reviews the difference between a DSS and a Management Information System as well as the DSS for airport planning developed by Zografos and Madas (2006).

2.3.1 Decision Support System versus Management Information System

We can differentiate a DSS from a MIS. A DSS usually has one or more data stores that provide information to support the decision. A DSS does not update the database that it uses as external data sources and it communicates directly with the decision maker. The decision maker is considered as part of the system and supplies the DSS with specific information defining the decision to be made. Figure 2.4 is a schematic of a generic DSS (Turban 2005).



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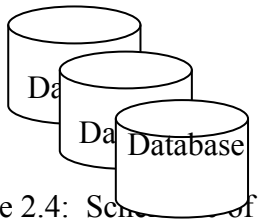

Figure 2.4: Sch[illegible] of a generic DSS (Turban, 2005)

The development process of a DSS is also different from that of a MIS because a Decision Support System is designed to solve semi-structured or unstructured problems. The DSS Development Process (DDP) is a set of procedures that is tailored to the development of a DSS, taking into account its need to solve semi-structured or unstructured problems. In the development of a Management Information System (MIS), a System Development Life Cycle (SDLC) strategy is used. This approach is different from that of a DDP. System Development Life Cycle (SDLC) strategy is a top-down design philosophy which assumed that the information requirements of a system can be pre-determined. In this approach, the exact needs and specifications of the system are determined first and then followed by the design and construction of a system that meet the needs defined. The SDLC gave a structure to a system design process. On the other hand, the DDP is an evolutionary design approach which based on prototyping and incremental development.

2.3.2 Decision Support System for Airport Planning

Zografos and Madas (2006) developed a decision support system known as the "Optimization Platform for Airports including Landside" or OPAL DSS for airport airside and landside capacity analysis. This integrated DSS is able to analyse airside

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and landside operations simultaneously and capture the tradeoffs between the airport performance measures by experimenting with various "what-ifs" scenarios.

The OPAL DSS architecture consist of a central database and four interacting modules addressing capacity and delays, environment, safety assessment and cost-benefit analysis. Each of these four modules has its own local database but it receives shared input data from a global central database and also writes its output to this central database. Data converters act as a middleware to communicate between the central database and each individual module so that the output of one module can be used as the input for other modules through this central database. Figure 2.5 illustrates the architecture.

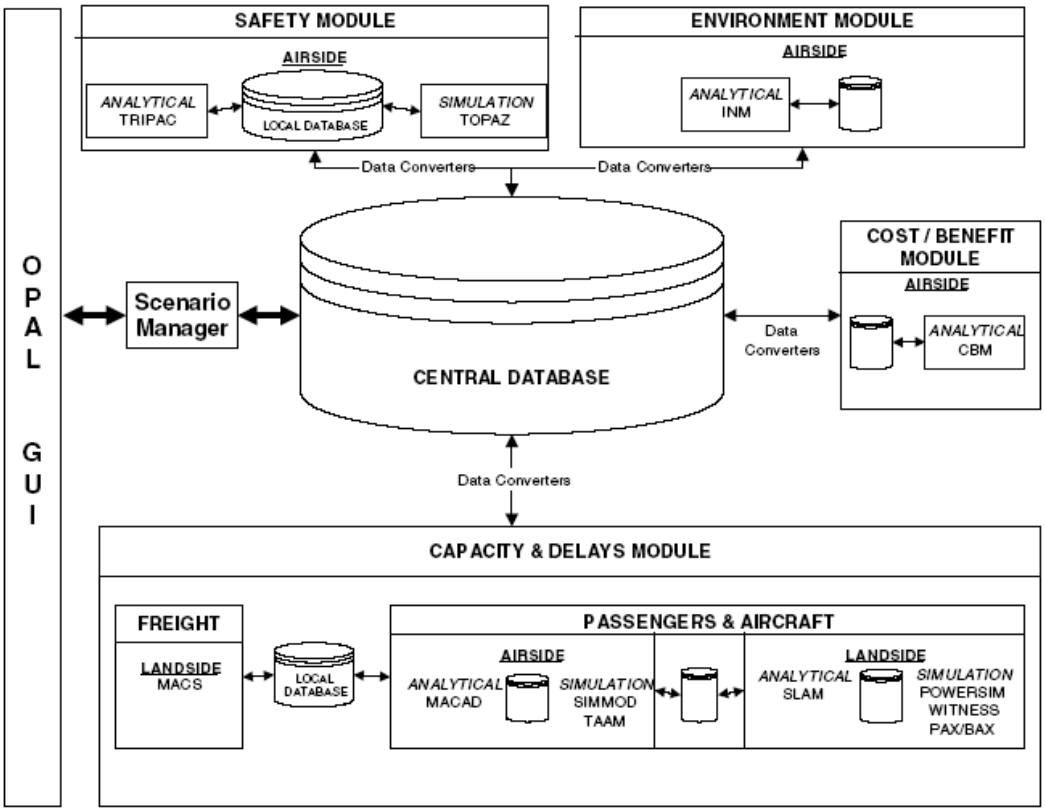

Figure 2.5: System architecture of OPAL DSS (Zografos and Madas, 2006)

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In the capacity and delays module, airside modeling is carried out using an analytical modeling software known as MACAD (MANTEA Airfield Capacity and Delay model) and the landside modeling is carried out using SLAM (Simple Landside Aggregate Model). Integration between MACAD and SLAM was achieved by sharing a common flight schedule stored on the central database. MACAD models the airside operations of the airport and yields results such as airside delays and stores the result in the central database. SLAM then takes into account the airside delays modeled by MACAD and the original flight schedule to calculate landside delays and the capability of the landside facilities to handle such delays. A delay in the arrival flight will often result in a delay to the connecting departing flights and these delays to the airside will affect the operations of the landside. In order to capture these chain effects, the OPAL DSS workflow involved a close-loop run of MACAD-SLAM-MACAD.

Zografos and Madas (2006) developed the OPAL DSS to analyse the effect of an increase in air traffic at Athens International Airport for the Olympic Games in 2004. Although the OPAL DSS could be used for landside and airside capacity planning, Zografos and Madas (2006) focused their study on airside capacity. They concluded that the most constraining factor of Athens Airport under an increased traffic situation will be the runway system. Arrival and departure delays could be as high as 12.5 minutes and 4.5 minutes respectively during the peak.

2.4 Research Gap

Fernandes and Pacheco (2002) felt that rule-of-thumbs developed by IATA and FAA are not applicable to Brazilian airports, especially those serving domestic traffic because their conditions and passengers perceptions of waiting time, congestions and service standards are different. As such, they used Data Envelopment Analysis (DEA)

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for airport landside capacity planning. DEA does not require that the functional form relating inputs to outputs be specified. Instead, it construct an 'efficient frontier' which is the benchmark for efficiency. Airports that are on this frontier are operating at capacity and need to expand its facility. The disadvantage of this method is that it can only determine relative efficiency with respect to airports that are being sampled.

Another limitation of using rule-of-thumbs is that parameters such as passenger processing rate are deterministic and this is not an accurate reflection of airport operations because it does not take into consideration variability in passengers inter-arrival time and processing rates. To overcome this problem, queuing theory was used. The essence behind queuing theory is that passengers arrive at some known rate governed by a probability distribution and are served with a service time that is also governed by another probability distribution.

Due to the high variability in the number of arrivals and departures over a typical day, queuing theory's steady state assumption is not valid for modeling an airport over a duration of a day. As such, some researchers propose to use the various branches of mathematical programming such as multistage stochastic programming and integer linear programming to analyse airport landside capacity planning. Although mathematical programming is able to model the variability in demand over the duration of a day, this method is very complicated to apply.

The DSS that Zografos and Madas (2006) developed uses demand aggregation as a basis for modeling an airport's landside. However, demand aggregation is unable to model the variability in service time at passenger processing point.

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Simulation is a simpler technique to model the variability in demand over the duration of a day because it mimics the actions of every passengers and the landside processes that they need to go through without having the need to develop analytical models. It is also able to model the variability in service time using probability distribution. However, the pitfall and limitation of simulation is that, airport planners or consultants working in developing countries frequently do not have any historical data that is essential for simulation (Appendix A). This challenge is compounded by the fact that they often do not have time to perform data collection. This is because they are under a tight deadline to complete their simulation and propose a recommendation as the airport is over crowded due to the explosive growth in air travel (Appendix A).

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CHAPTER 3

DECISION SUPPORT SYSTEM FRAMEWORK FOR AIRPORT LANDSIDE CAPACITY PLANNING

The previous chapter reviewed methods used to size the landside capacity of an airport as well as various research conducted on this subject. Each of these method has its advantages and disadvantages. This chapter provides the rationale behind using a simulation based decision support system to determine airport landside capacity. It also developed a framework for a DSS for the domain of airport landside capacity planning. This framework consist of the components that made up a DSS for airport landside capacity planning and also steps for the development of a DSS for airport landside capacity planning.

3.1 Rationale for Using Simulation Based Decision Support System

The analysis of an airport's landside capacity is a complex task. This is because the behavior of passengers and their processing time at each passenger processing facility is different and is dependent on a combination of factors. The resources to operate these passenger processing facility also changes according to the shift schedule of ground handling agents and the various parties involved in the passenger handling process. The complexity of the model called for simulation as the suitable tool that can yield accurate result. Simulation requires input parameters for the model to be accurate. However, many organizations do not have a systematic way to archive data that is necessary for simulation (Sprague & Carlson, 1982). In addition, the results produced by a simulation model is voluminous and a lot of time and effort is required to sift

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through results that are insignificant to decision making. A DSS can overcome these problems and assist airport planners in their decision making process.

A DSS is an interactive computer-based information system, developed to support the decision making process of a complex problem. Turban (2005) identifies the key capabilities of a DSS as a system that supports modeling and analysis (Turban, 2005). The characteristics of a simulation model and a DSS suggest that combining both methods is an effective way to overcome the challenges of airport landside capacity planning.

3.2 Application Case- Singapore Changi Airport Terminal 2

In this study, Singapore Changi Airport's Terminal 2 will be used as an example for developing the DSS framework as well as for simulation modeling. Singapore Changi Airport has a total of 4 terminals- Terminals 1, 2,3 and Budget Terminal. Changi Airport won a total of 25 "Best Airport" awards by various leading travel organisations and magazine in 2007. The airport had a operating surplus of S$398 million in financial year 2005/2006 (Civil Aviation Authority of Singapore, 2006). The Civil Aviation Authority of Singapore (CAAS) is a statutory board under the Ministry of Transport that operates all the terminals in the airport.

Singapore Changi Airport's Terminal 2 started operations in 1990. It is served by 13 airlines and has an area of 358,000 square meters with a total of 35 contact gates. It has a design capacity of 23 million passenger per annum and operated at 89% of its design capacity in 2006 (Civil Aviation Authority of Singapore, 2007). Terminal 2 adopts a central terminal-pier finger design. This means that centralised processing can be done

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for almost all passenger handling processes at the central terminal while aircraft are docked at the pier. Figure 3.1 illustrates the layout of Terminal 2.

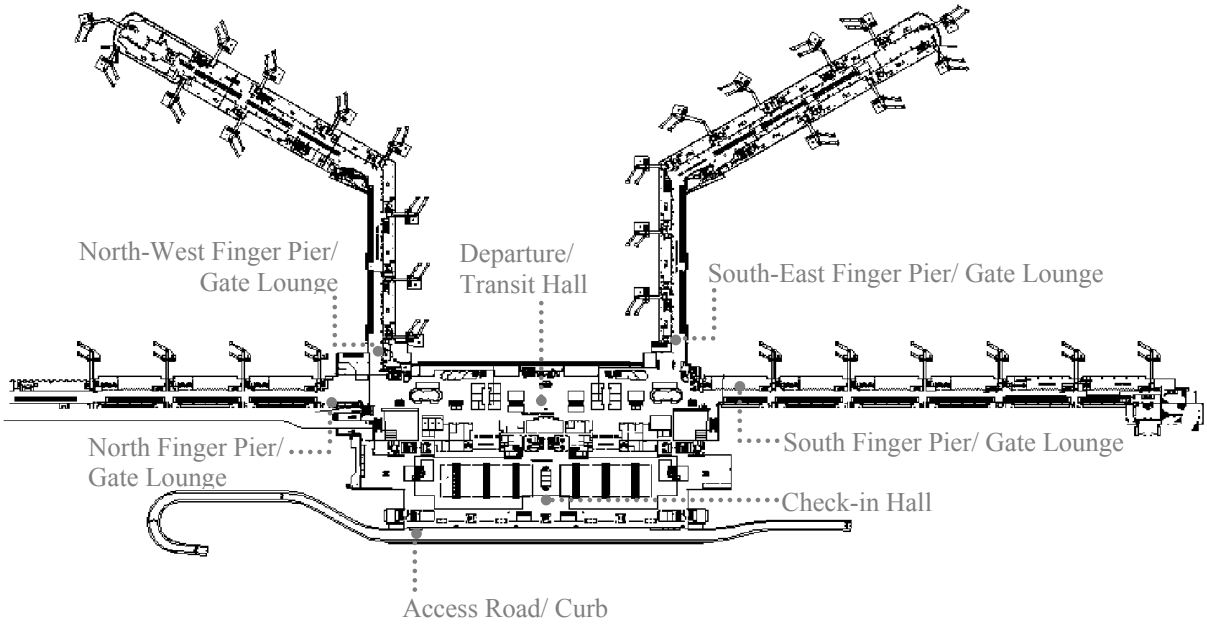

Figure 3.1: Layout of Singapore Changi Airport's Terminal 2 (Courtesy of CAAS)

Planning

A DSS is made up of the data management sub-system, model management sub-system and user interface sub-system (Turban, 2005). This section presents the structure of each of these sub-system using Changi Airport Terminal 2 as an example.

3.3.1 Data Management Sub-system

The data management sub-system is a database that will contain data for the simulation model of Changi Airport's Terminal 2. It shall be interfaced with Changi Airport's Airport Operational Database (AODB) which is a repository of operational data collected through each day of operation. The AODB would store data such as flight schedule, aircraft gate allocation and processing time of passenger at each processing

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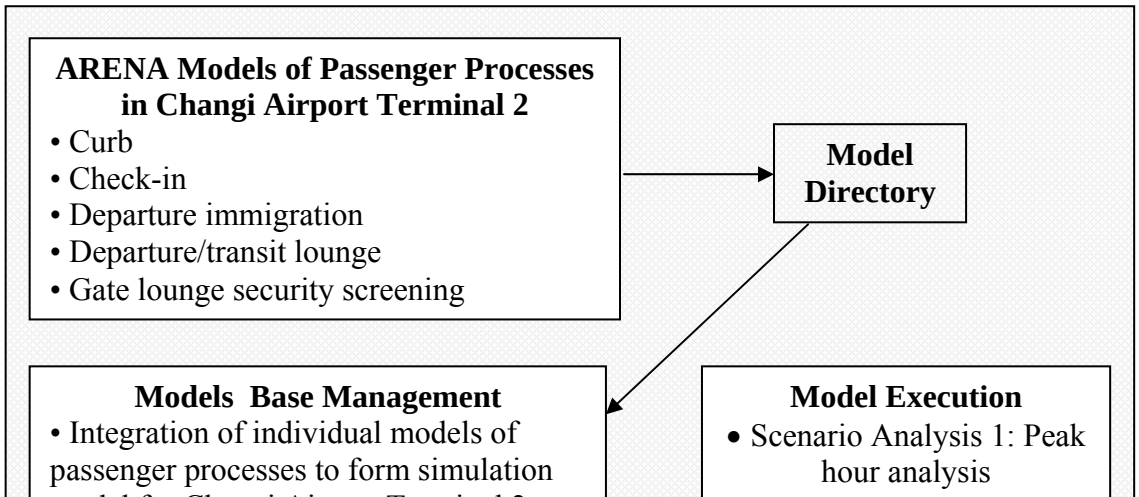
point. The data management sub-system is required to store the input parameters that are required by the simulation model in the model management sub-system. A comprehensive list of the data that is stored in the database management sub-system is listed in Appendix B .

3.3.2 Model Management Sub-system

The model management sub-system contains the simulation model of the landside processes of Changi Airport Terminal 2. A commercial-of-the-shelf (COTS) simulation software, ARENA will be used to create the simulation model. It has the capability for generating reports on the output of the simulation and update the model through Visual Basic for Applications (VBA).



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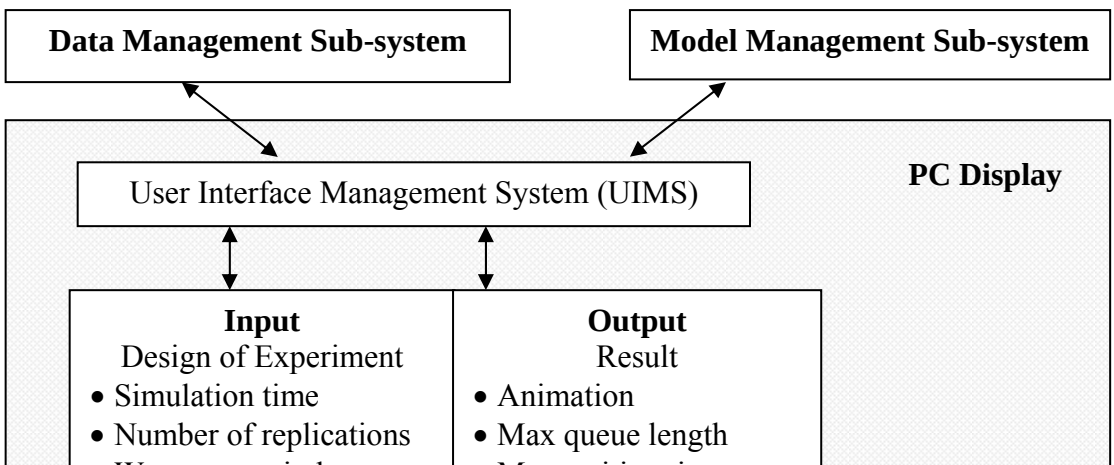
3.3.3 User Interface Sub-system

The user interface sub-system provides a user friendly way to interact with the model management and data management sub-systems. The user provides parameters needed in the design of the simulation experiment via dialogue box, pull-down menus and buttons. Parameters needed for the design of experiment are the simulation time, number of replications, warm up period and simulation terminating condition. The user interface sub-system would also filter simulation results such that the user will only see results that are significant to decision making. Results that are significant to decision making are the maximum queue length and waiting time at a passenger processing facility, the maximum density in the gate lounge and the maximum flow rate along a flow corridor. The user is considered as part of the system and interacts intensively with the computer.



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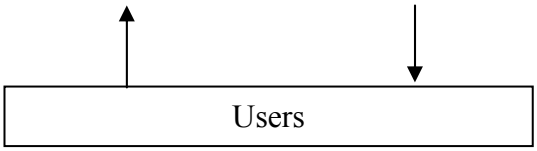

Figure 3.3: : Schematic of the user interface sub-system for Changi Airport Terminal 2 landside capacity planning DSS (adapted from Turban, 2005)

3.4 Steps for Developing a DSS for Airport Landside Capacity Planning

Figure 3.4 presents the steps and deliverables for the development of a DSS for airport landside capacity planning using Changi Airport Terminal 2 as an example. It is an adaptation and integration of Oaksott's (1997) methodology of simulation modeling and Holsapple & Whinston's (1996) DSS Development Process (DDP).

The fundamental concept behind the DDP is an evolutionary design approach which is based on prototyping and incremental development (Holsapple & Whinston's, 1996). There is no need to develop a design for the complete system. A preliminary design for a subset of the desired functionality of the DSS is sufficient for implementation of a prototype. The iterative process of system design-prototype implementation will eventually lead to a complete DSS.

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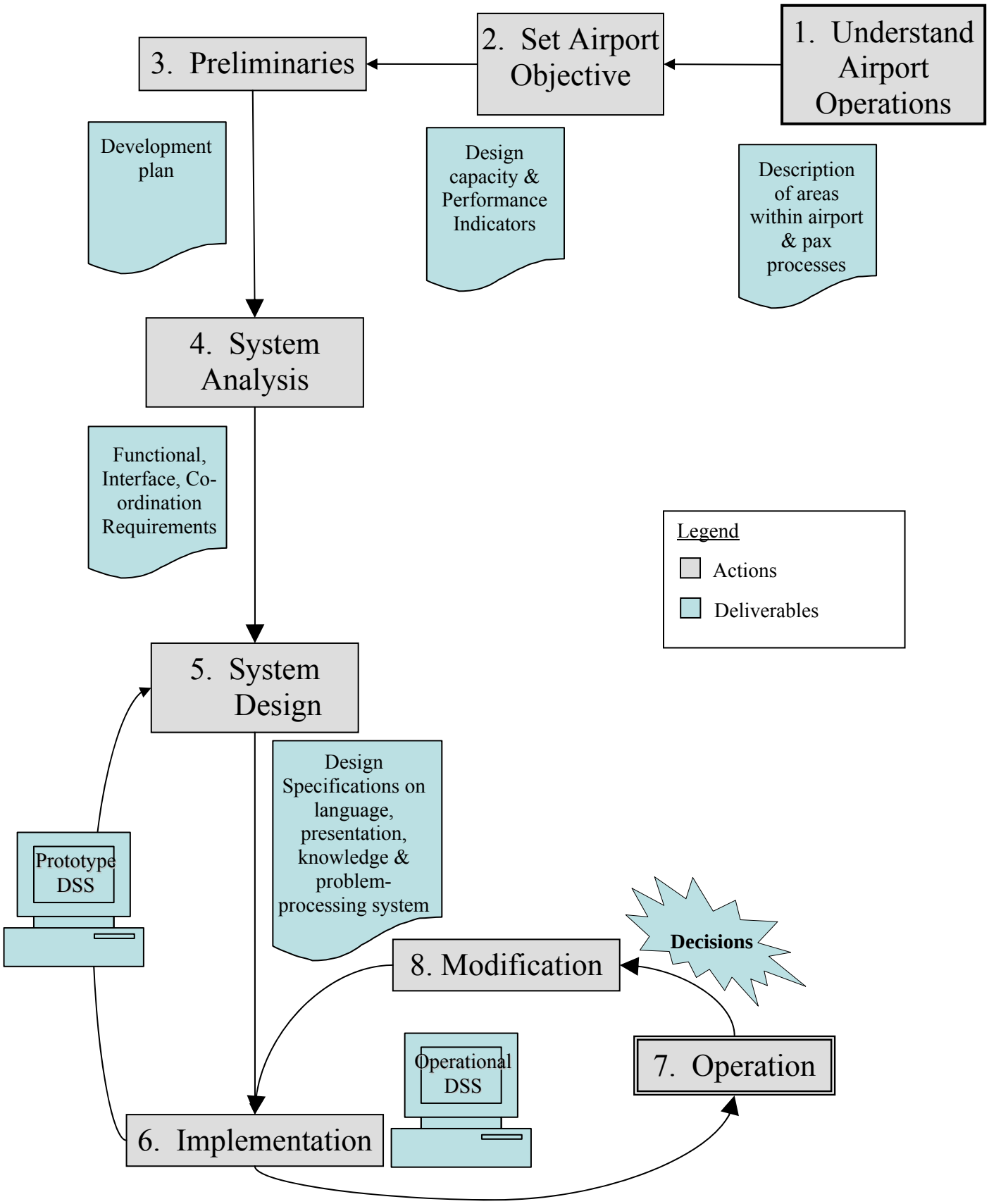

Figure 3.4: Steps in the development of DSS for airport landside capacity planning

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3.4.1 Understand Airport Operations

The first step to developing a simulation based decision support for airport landside capacity planning is to understand the airport under study. A visit to Changi Airport Terminal 2 was conducted. An interview with the Head of Operations for Terminal 2 was carried out to understand the use of different areas in the airport and they are summarized below. The structure of the interview and interview notes are attached as Appendix A of this thesis.

a. Different areas in Changi Airport Terminal 2

i. Curb

Vehicles stop along the curb and passengers will alight and unload their bags from the vehicles before entering the departure hall. Tour bus will stop at Entrance 4.

ii. Check-in Hall

The check-in queue discipline adopted is a single queue system where one queue is served by many counters. The Kendall notation is M/G/*s*. At the check-in counter, passenger's documents are checked and they are assigned a seat on the aircraft. Their baggage are also accepted by the ground handling agent. The number of check-in counters that are in use varies with the shift pattern of the ground handling agent.

iii. Immigration

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The immigration queue discipline adopted is a multiple queue system where there are may counters and passengers will queue in front of each counter. The Kendall notation for this queue is M/G/1. Passengers will have their travel documents checked by the immigration officer.

iv. Departure/ Transit Hall.

The departure/ transit hall is where passengers are free to visit shops and food and beverage outlets or wait before boarding the aircraft.

v. Gate Lounge

Pre-board security screening is carried out before passengers enters the gate lounge. Cabin bags are screened and passengers walked through a metal detector. The gate lounge is opened 1 hour before the flight's Estimated Time of Departure (ETD).

The interview also yielded a detailed understanding on passengers and well-wishers processes. These information are summarized below and the structure of the interview and interview notes are attached as Appendix A of this thesis.

b. Movement of Passengers and Well-wishers

i. Originating Passengers

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Originating passengers are travelers who start their journey in Singapore. Originating passengers will enter the airport's departure hall from the curb, the bus station, and the train station. Each car that arrives at the curb carries an average of 3 passengers. The first originating passengers arrive at the airport 2.5 hours before flight departure while passengers traveling as a tour group arrives 2 hours 20 minutes to 2 hours before departure. Originating passengers will then check-in before going through immigration formalities before entering the departure/transit lounge. The time they spend in the departure/transit lounge will depend on the departure time of their flight.

ii. Transfer Passengers

Transfer passengers are travelers who come to Singapore to connect to another flight. Transfer passengers will deplane and proceed for security screening before they enter the departure/transit lounge. The time they spend in the departure/transit lounge will depend on the departure time of their connecting flight.

iii. Terminating Passengers

Terminating passengers are travelers who end their journey in Singapore. Terminating passengers will deplane and go through arrival immigration before entering the baggage claim area.

iv. Well-wishers

Well-wishers are members of the public who go to the airport to see passengers off. Like originating passengers, well-wishers will enter the airport's departure

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hall from the curb, car park, bus station or train station. They will meet originating passengers and accompany them until they leave the check-in hall for immigration. Nearly all well-wishers will then leave the airport terminal by the same mode of transport that they took to the airport. Although well-wishers do not use any of the airport's landside facility, they do contribute to the problem of congestion and thus have an impact on the Level of Service.

The layout of Changi Airport Terminal 2 and the authorization to use the layout for the animation of the simulation model was also obtained from the Deputy Director of CAAS Engineering and Real Estate Division. The number and location of resources such as check-in counters, immigration counters were obtained from the layout. In addition, the area of gate lounge and width of flow corridors were also obtained from the plans. These will be used for building the simulation model and analysing the results of the simulation later.

3.4.2 Set Airport Design Objective and Performance Indicators

Changi Airport Terminal 2 is designed with the objective to handle 23 million passengers per annum and 4,900 passengers per hour during the peak (Appendix A). There are many definition of peak hour (de Neufville, 2003) and CAAS uses the 40th busiest hour of the year as the design peak hour. This definition ensures that airport facilities have adequate capacity to handle demand throughout the year while not being over designed just to handle a few instances when extreme peaks may occur (de Neufville, 2003). The performance indicators are maximum queue length at passenger processing facilities, maximum waiting time at passenger processing facilities, congestion level of gate lounge and congestion level of flow corridors. Due to

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confidentiality reasons, quantitative values for the above performance indicators could not be revealed.

3.4.3 Preliminaries

The basic types of knowledge to be handled by the DSS is identified. There are two categories of basic knowledge, they are descriptive or procedural knowledge (Holsapple & Whinston, 1996). In the case of Changi Airport Terminal 2 landside capacity planning DSS the basic type of knowledge is procedural as it deals with the landside processes that passengers will come across from check-in until they board the aircraft.

A development plan including a schedule of activities, budget, a list of people and their roles in the development of the DSS either as knowledge sources or as users is documented. In the case of Changi Airport Terminal 2 landside capacity planning DSS, the people who are knowledge sources are airport managers from the Airport Operations division while users of the DSS are airport planning engineers from the Engineering and Real Estate division. A schedule of activities and budget is not documented as it has no practical usage in this thesis.

3.4.4 System Analysis

System analysis can be divided into three parts. They are functional requirements, interface requirements and co-ordination requirements (Holsapple & Whinston, 1996).

a. Functional Requirements

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Functional requirements characterize the DSS's capabilities for storing, recalling, and producing knowledge (Holsapple & Whinston, 1996). Blanning (1979) classified the functions of a DSS under the categories of selection, aggregation, estimation, simulation, equalization and optimization. In the case of Changi Airport Terminal 2 landside capacity planning DSS, the functions of aggregation and estimation and simulation are required.

Aggregation is a derivation of summary statistics such as totals, averages, and frequency distributions (Blanning, 1979). The function of aggregation will summarize statistics which is stored in the database management sub-system, such as converting the number of passengers that uses different ground access mode into percentage.

Estimation is a derivation of estimates for values of parameters in a model such as a probability distribution function (Blanning, 1979). In the case of Changi Airport Terminal 2 landside capacity planning DSS the function of estimation will transform data such as the processing time of each passenger into a probability distribution function. These probability distribution functions are input parameters for the simulation model in the model management sub-system.

Simulation is a derivation of knowledge about expected consequences of taking an action or of changes in the model's environment (Blanning, 1979). In the case of Changi Airport Terminal 2 landside capacity planning DSS the function of simulation is performed by the simulation software, ARENA.

b. Interface Requirements

The interface requirements will shape the DSS knowledge-communication capabilities (Holsapple & Whinston, 1996). It states the type of request the user interface sub-

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system of the DSS is required to interpret and the responses that it must present. In the case of Changi Airport Terminal 2 landside capacity planning DSS, user request shall be selected from a list in a dialogue box and the user interface sub-system of the DSS is required to present numerical data.

c. Co-ordination Requirements

The co-ordination requirements describe the timing of functional events as it may be necessary for one functional event always to precede some other functional event (Holsapple & Whinston, 1996). In the case of Changi Airport Terminal 2 landside capacity planning DSS, the functions of aggregation and estimation must precede the function of simulation. This is because the result from the functions of aggregation and estimation is subsequently used for the function of simulation.

After identifying the functional, interface and coordination requirements, the candidate tools for DSS development will be identified. Candidate tools are software packages or languages that allows functional, interface and coordination requirements to be met (Holsapple & Whinston, 1996). In the case of Changi Airport Terminal 2 landside capacity planning DSS, ARENA has been chosen as the tool to perform the function of simulation. ARENA was chosen for its intuitive graphical user interfaces, menus and dialogues. A possible candidate tool for the database will be SQL (Structure Query Language) and the user interface can be a web browser such as Internet Explorer. Candidate tools for the database and user interface are not evaluated as it does not form the scope of this study.

3.4.5 System Design

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System design is organised in terms of DSS architectural elements. The architectural elements of a DSS is language system design, presentation system design, knowledge system design and problem-processing system design (Holsapple & Whinston, 1996).

The language system characterize various request that a user will be allowed to make (Holsapple & Whinston, 1996). In the case of Changi Airport Terminal 2 landside capacity planning DSS, users will make queries on maximum queue length and waiting time at passenger processing facilities, congestion level of gate lounge and congestion level of flow corridors. These queries shall be made by selecting from a list in a dialogue box.

The presentation system characterize the response to a problem handling request (Holsapple & Whinston, 1996). In the case of Changi Airport Terminal 2 landside capacity planning DSS, the result of a query shall be presented as a numerical value in a table, a bar graph and a line graph.

Designing the DSS's knowledge system begins with choosing the knowledge representation techniques that will be adopted (Holsapple & Whinston, 1996). The procedural knowledge of Changi Airport Terminal 2 landside capacity planning DSS is represented by a flow chart in Figure 3.5. This flow chart is also used for conceptualizing the simulation model of Changi Airport Terminal 2. Model conceptualization involves deciding the level of detail that is appropriate for the simulation model. With the knowledge of the level of detail, the database schema of the database management sub-system can be designed. The data that is required to be stored in Changi Airport's Terminal 2 landside capacity planning DSS's database sub-system is listed in Appendix B. However, design of a database schema is not part of the scope of this study.

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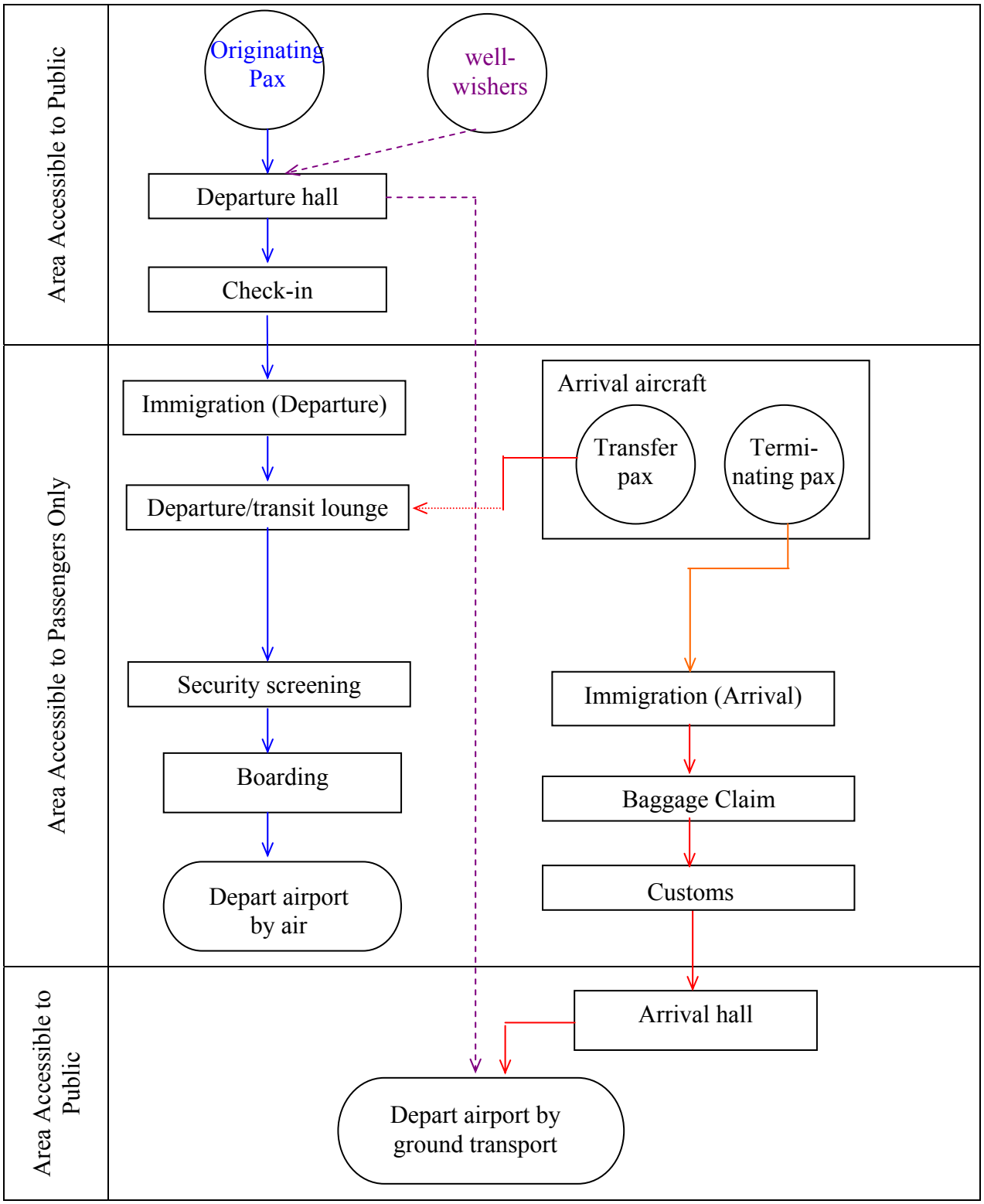

Fig 3.5: Flow chart depicting passengers flow in Changi Airport Terminal 2.

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Problem-processing system design consists of determining the flow of instructions that need to be given to the computer in order for it to handle the contents in the language system, presentation system, knowledge system and problem-processing system (Holsapple & Whinston, 1996). There are various DSS generators that provide pre-designed problem-processing system. A DSS generator is a DSS development software that integrates several DSS development tools into one package (Turban, 2005). DSS generators are not evaluated as the development of the complete DSS is not part of the scope of this thesis.

3.4.6 Prototype Implementation

A prototype DSS is implemented to demonstrate in a small scale and in a partial way the functions of a complete DSS. The flow chart in Figure 3.5 developed during the knowledge system design is translated into a simulation model using ARENA. Since the DSS Development Process (DDP) is based on incremental development, each landside process is modeled, tested, and deployed for use before the next landside process is added to the simulation model. For example, the processes at the curb is modeled, tested and deployed for use before the check-in process is modeled. Chapter 4 presents the details on model translation.

The prototype simulation model of Changi Airport Terminal 2 is tested using two methods. They are model verification and model validation. Model verification refers to the task of ensuring that the model behaves as intended and there are no bugs in the simulation model. Model validation refers to the task of ensuring that the model behaves in the same way as the actual system would under the same conditions (Kelton *et al*, 2002). Entities are created and the animation is closely observed to see if the model behaves as intended. The prototype is corrected and refined before the scope of

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the DSS is expanded. The iterative process of system design-prototype implementation will eventually lead to a complete DSS.

3.4.7 Operation

During its operations, the Changi Airport Terminal 2 landside capacity planning DSS shall support airport planners in making decisions concerning airport landside capacity. Airport planners will carry out scenario analysis and will need to design simulation experiment for each different scenario. In this study, two scenario analysis would be carried out. The details of the scenario analysis such as the design of experiment is presented in Chapter 5. Design of experiment involves deciding the number of replications and warm up period before the simulation model is run. The number of replications refers to the number of simulation runs carried out. This is important because simulation is essentially an elaborate sampling tool and more number of replications will lead to increase accuracy. The warm up period is the duration of the simulation that is required for the system to reach steady state. No statistics will be collected during the warm up period.

In preparation for the completed DSS to be deployed into the working environment, users must be trained and manuals must be ready. These manuals should include the purpose of the DSS, its features, capabilities, limitations, assumptions and change management procedure. As the scope of this study does not include the development of the complete DSS, the user manual for the complete DSS is not written. However, the user manual for the simulation model is written and attached as Appendix C.

3.4.8 Modification

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It is common that changes would be needed on the DSS within its operating life (Holsapple & Whinston, 1996). For example, modification need to be made to the knowledge system's simulation model and database when there is a change in passenger process due to stricter security requirements. The simulation model would be changed to simulate the new security process passengers had to go through while another table would be added to the database to capture the processing time of this new process.

Good system administration practices for the DSS must also be employed (Holsapple & Whinston, 1996). These includes user access rights and change management. Different level of access rights can be set such that some users can use the DSS to change input data such as flight schedule while other users are restricted to only making queries. The DSS system administrator will also ensure that change management procedures are adhered to and documented when any modification is made.

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CHAPTER 4

SIMULATION MODEL DEVELOPMENT

This chapter models the movement of originating, transfer, terminating passengers and well-wishers through different passengers processing facility using a commercial-of-the-shelf (COTS) simulation software, ARENA. ARENA is a high level simulator software featuring intuitive graphical user interfaces, menus and dialogues. A simulation model is developed by dragging and dropping modules representing, processes, decision etc from a Panel into a Model Window (Appendix D). Connectors join these modules to form a flow chart of the process being simulated. Before running the simulation, ARENA would go through a compilation process whereby the high level flow chart would be converted into a low level simulation language known as SIMAN. These user-friendly features of ARENA's interface makes model development simple. In addition, the model could also be updated with ease as operational procedures change and evolved over the years. ARENA also offers the flexibility of programming parts of the simulation model in either SIMAN or Visual Basic for Applications (VBA). Appendix E summaries the commonly used ARENA modules that has been used for model translation. A screen shot of the model and the animation is presented in Appendix F and Appendix G respectively.

4.1 Modeling Originating Passengers

Originating passengers are travelers who start their journey in Singapore. This section describe in details how originating passengers are modeled and the processes that they go through.

4.1.1 Import Departure Flight Schedule and Passengers Attribute

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Figure 4.1 shows how flight schedule and passengers' attributes are imported from an external file. These attributes that are assigned to the passengers will be used in other parts of the model. A control entity is created at the start of the simulation (i.e. simulation time 0.00). This control entity will read the departure time of the next flight using the READ module. The DELAY module will then hold the entity until the simulation clock reaches the time the first passenger of the flight arrives at the airport. For Changi, this is approximately 2.5 hours before the departure time of the flight (Appendix A). Once the delay process is completed, the SIGNAL module will send a signal to the HOLD module in the well-wishers sub-model so that the control entity for the well-wishers will be released.

The SEPARATE module will duplicate another control entity so that it could read attributes associated with passengers who are on tour groups. This is for the purpose of simulating group check-in which will be described in detail in the later section.

The original control entity will continue to read the number of originating passengers on the flight, the check-in row assigned to process the originating passengers, the boarding gate of the aircraft and the airline. The airline or its ground handling agent will decide where passengers check-in and the priority check-in arrangement made for First and Business class passengers since different airlines have different operational requirements.

The next SEPARATE module sends the control entity back to the READ module to read the departure time of the next flight. This module will also duplicate the control entity by the number specified in the external file which the "READ no of pax" module reads from. These duplicates will now be modeled as passengers.

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The DECIDE module will separate these passengers into First, Business and Economy Class. The three ASSIGN modules that follows it, will assign a attribute and a different colour to the three classes of passengers so that they could be easily differentiated in later parts of the model and easily identified in the animation.

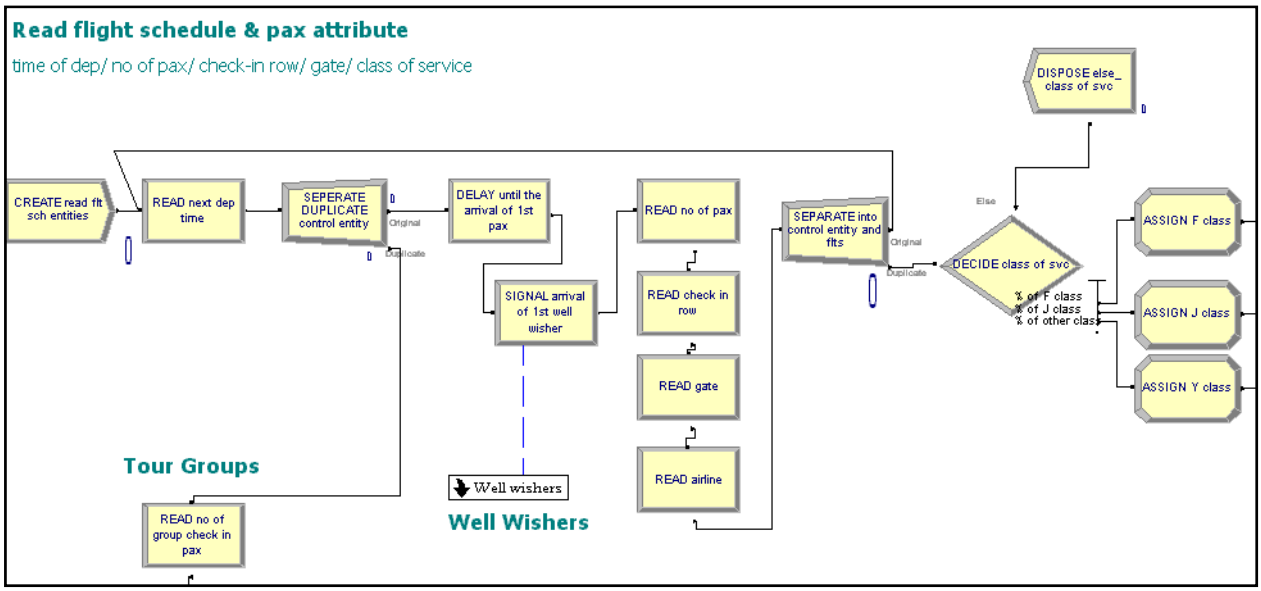
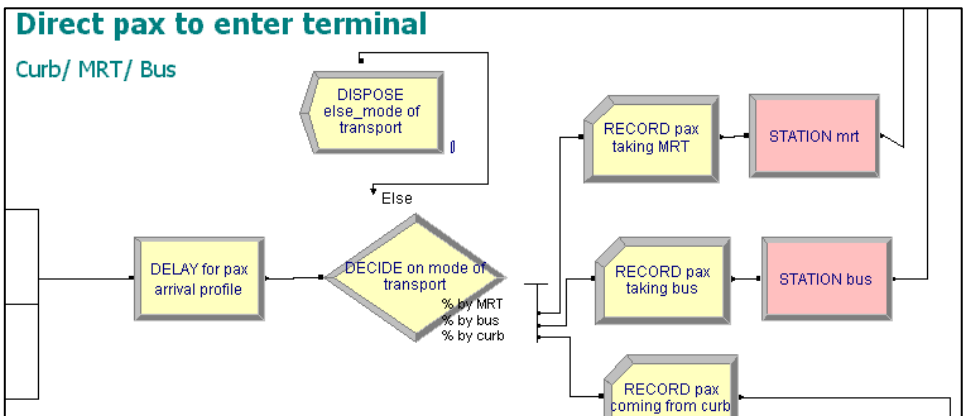


Figure 4.1: Importing flight schedule and passengers attribute

4.1.2 Modeling Passenger Split for Different Ground Access Modes

The DELAY module will model passengers arriving at the airport at different time according to a probability distribution (Figure 4.2). The DECIDE module will then split passengers according to their mode of transport to the airport. The STATION module correspond to points in the airport terminal where passengers will enter the airport. Passengers who come by private transport to the airport will enter the terminal from the curb. The next section will describe this in details.



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4.1.3 Modeling Activities at the Curb

Figure 4.3 shows the simulation logic used to model passengers arriving at one of the four curb entrances. Data collected in Changi showed that each car will send an average of 3 passengers to the airport (Appendix A). The BATCH module groups 3 passengers as one representative entity. In addition, First Class passengers on Singapore Airlines will use only Entrance 1 (Appendix A) and they are not batched with other passengers. The ASSIGN module then changes the picture of the representative entity into that of a car. Next, the RECORD module will record the number of vehicles using the road in front of the airport's entrance and the STATION module corresponds to the start of the road leading to the airport curb entrances. The next DECIDE module directs First Class passengers on Singapore Airlines to Entrance 1 while another DECIDE module directs the rest of the passengers to one of the four entrances. This is done according to the percentage specified in the DECIDE module. The ROUTE modules will animate these vehicles moving from the start of the roadway to the entrance.

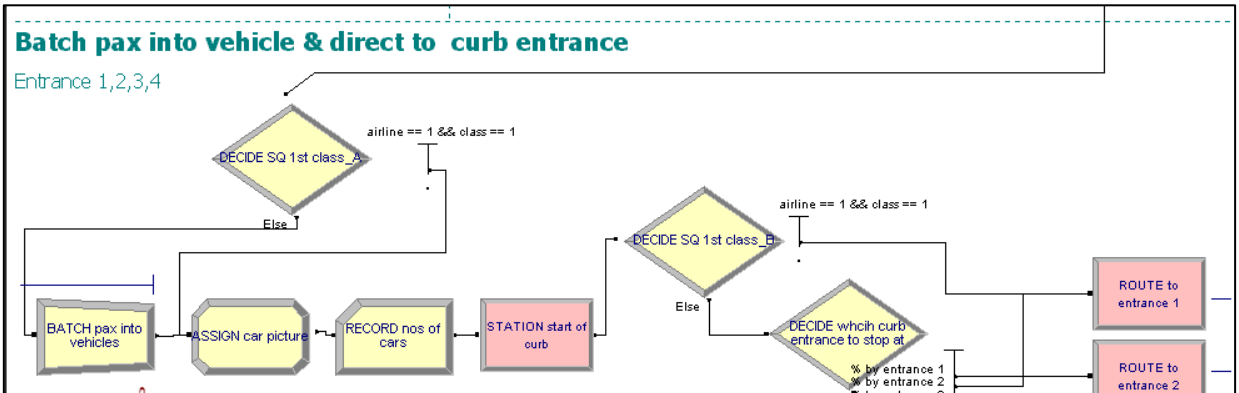

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Figure 4.3: Modeling vehicle arrivals at the curb

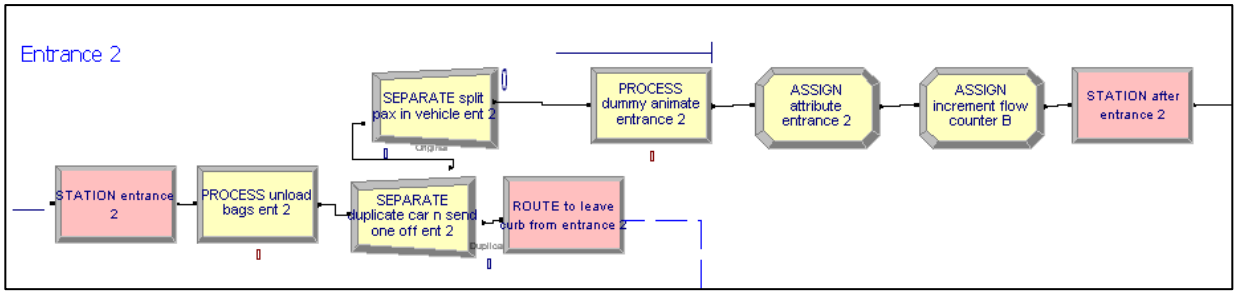

Figure 4.4: Modeling process at the curb

Figure 4.4 shows the logic that simulates passengers unloading their bags from a car, and the car leaving the airport. The PROCESS module is used to simulate passengers unloading their bags from the car. This will cause the car to incur a delay time which is a random variable. The SEPARATE module then duplicates the car and sends the duplicate to the end of the airport roadway using the ROUTE module. The original batched entity (represented by the picture of a car) will be split into passengers using the SEPARATE module. The next PROCESS module is a dummy module used to delay the passengers by 3 seconds. This will ensure that the passengers are visible during the animation. The time incurred by this dummy PROCESS module is non-value added, which is to say that it will not be computed as part of the process time. The ASSIGN module that follows increase the flow counter that measures the number of passengers passing through the entrance per five minutes. This is used to measure the congestion level at the entrance.

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4.1.4 Modeling Group Check-in Operations

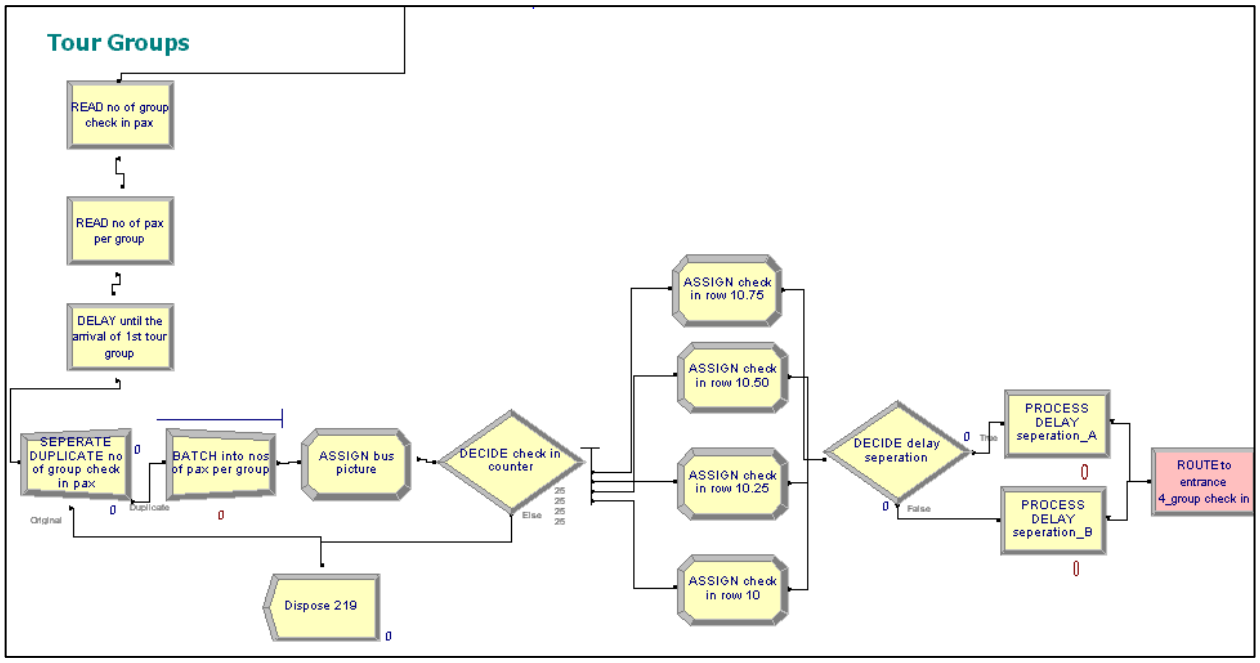

Figure 4.5: Modeling group check-in

Passengers in a tour group will be modeled to enter the airport from Entrance 4 and check-in at a dedicated check-in row. Figure 4.5 showed the simulation logic behind group check-in. The duplicated control entity mentioned in Section 4.1.1 reads the total number of group check-in passengers and the average number of passengers per group by using the READ module. The DELAY module will then hold the entity until the simulation clock reaches the time the first tour bus arrives at the airport. For Changi, this is approximately 2 hours 40 minutes before the departure time of the flight. Next, the SEPARATE module duplicates the control entity by the number specified in the external file which the "READ no of pax" module read from. These duplicates will now be modeled as passengers. The BATCH module then combine these passengers into groups, thus representing a tour group. The batched entity will be assigned a picture of a tour bus by the ASSIGN module. The set of DECIDE and ASSIGN modules direct the tour group to one of the dedicated group check-in counters. It is

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found that tour groups will normally check-in between 2 hours 20 minutes and 2 hours before the departure of a flight, hence the next set of DECIDE and DELAY modules following this model the tour groups coming between 2 hours 20 minutes and 2 hours before the departure time of the flight. Finally, the ROUTE module directs the tour bus to Entrance 4.

4.1.5 Modeling Passenger's Choice of Check-in Row

The Terminal 2 Baggage Handling System has the capability to enable universal check-in (Appendix A). This means that any check-in row can serve all flights operating from it. Figure 4.6 shows how this is simulated.

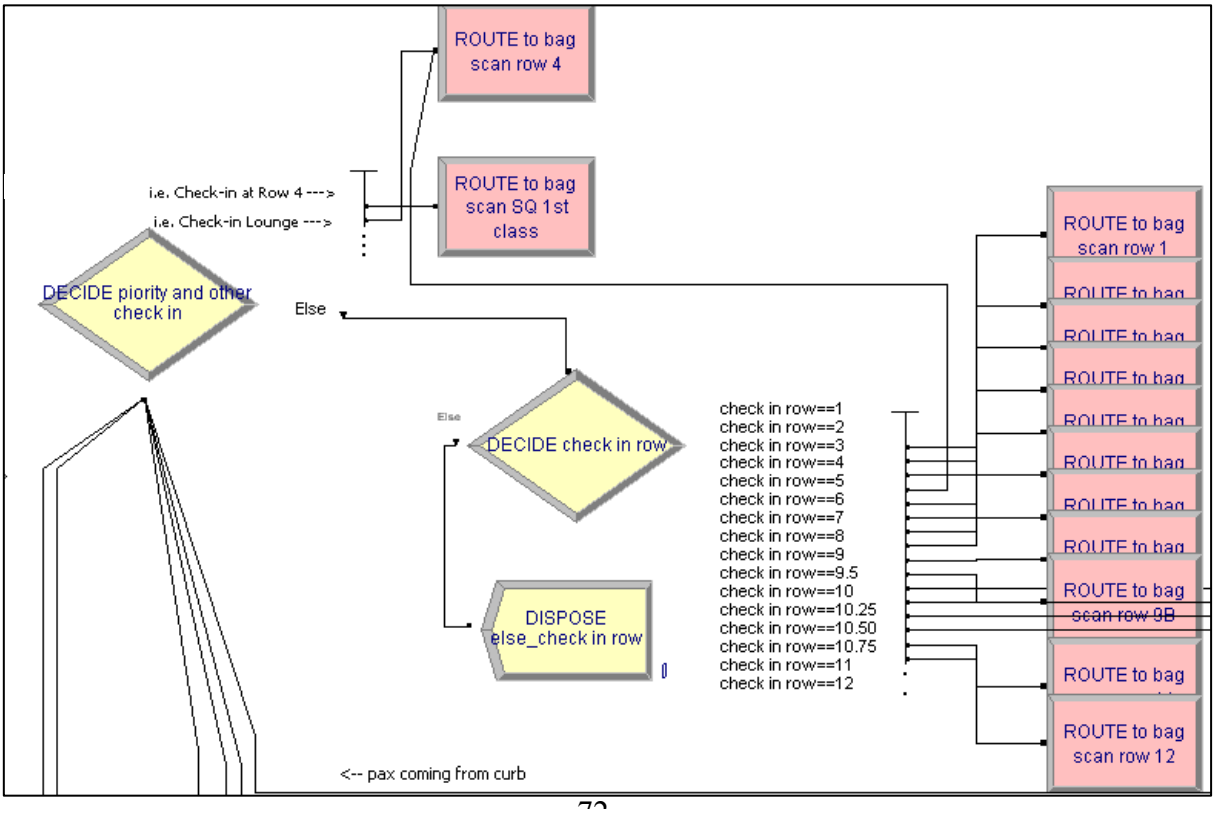

Figure 4.6: Modeling passengers choice of check-in row

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Passengers from the curb, bus station and train station will arrive at the DECIDE module. The first DECIDE module will test the passenger's 'airline' and 'class' attribute in order to determine which row they should go to check-in. Row 4 is reserved for Business Class passengers whose airline is a member of Star Alliance. It is also reserved for Star Alliance member's First Class passengers except Singapore Airlines First Class passengers who have a separate check-in lounge. The rest of the passengers will be routed to their check-in row by the second DECIDE module.

4.1.6 Modeling Check-in Operations

The queue discipline for the check-in process is a single-queue system and passengers are being served on a first-come-first-serve basis. There is only one queue and many counters will serve that queue. The Kendall notation is M/G/s. The inter-arrival rate of passengers at the check-in is random, the process time is an empirical distribution and the number of servers varies with the queue length (Appendix A).

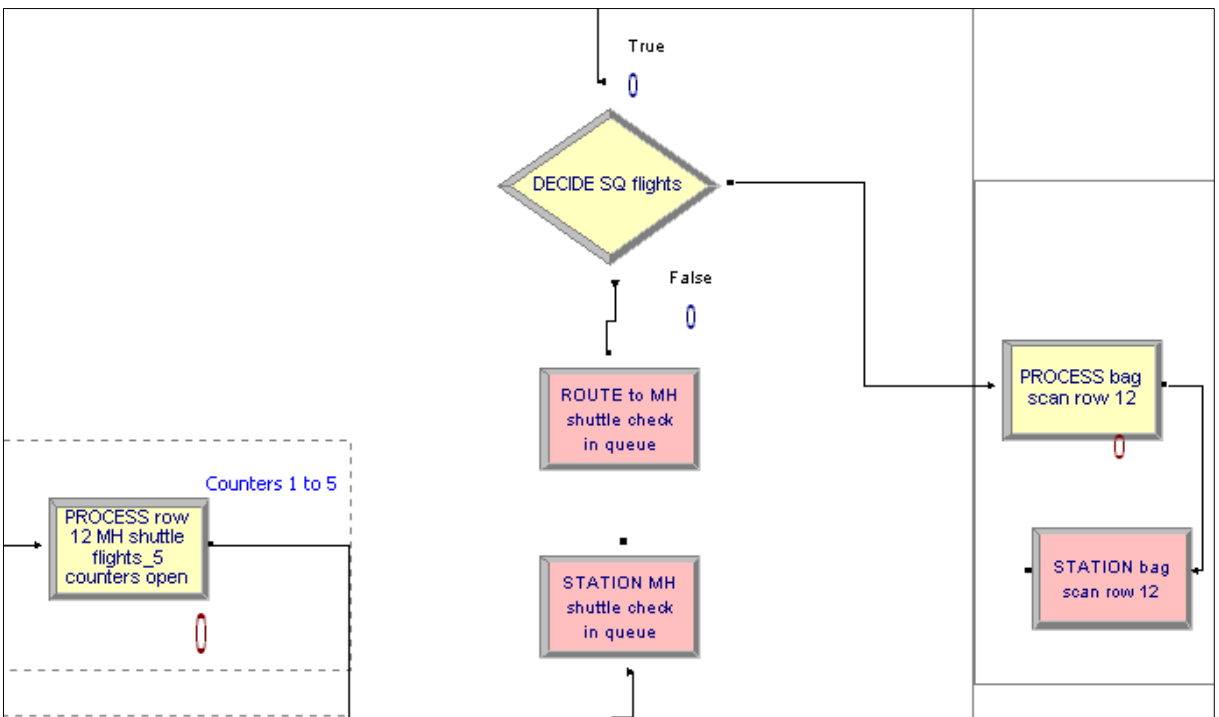

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Figure 4.7 shows the simulation logic behind a typical check-in row. The ”DECIDE open more counters” module will determine the number of counters to open based on the number of passengers waiting to be served. It will test the queue length and increase or decrease the resource (i.e. number of check-in staff) when the queue length exceeds or falls below a certain specified number. There are 12 check-in counters in one row and the PROCESS module has a set of resource with 0 to 12 members, thus simulating the number of counters that are open. Passengers will be routed to the immigration area once they have completed check-in.

4.1.7 Modeling Immigration Operations

Figure 4.8 shows the simulation logic behind the operations at the immigration counter. The queue discipline for the immigration counter is different from that of the check-in. There are may immigration counters and passengers will queue in front of each counter. The Kendall notation for this queue is M/G/1 (Appendix A). The distribution of inter-arrival times is Markovian because it is random as it is dependent on the previous

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process. The process time is a triangle distribution with a minimum time of 7 seconds, a maximum time of 58 seconds and a typical time of 11 seconds (Appendix A) and each queue has one server. To simulate passengers picking the shortest queue, the PICKSTATION module test the queue condition of each immigration counter and route the passenger to the counter with the shortest queue. The PROCESS module models the immigration staff checking the passport of the passengers. A process time will be incurred here. Next, the ROUTE module will animate these passengers moving to a point behind the immigration counter before they start their activities in the departure/transit hall.

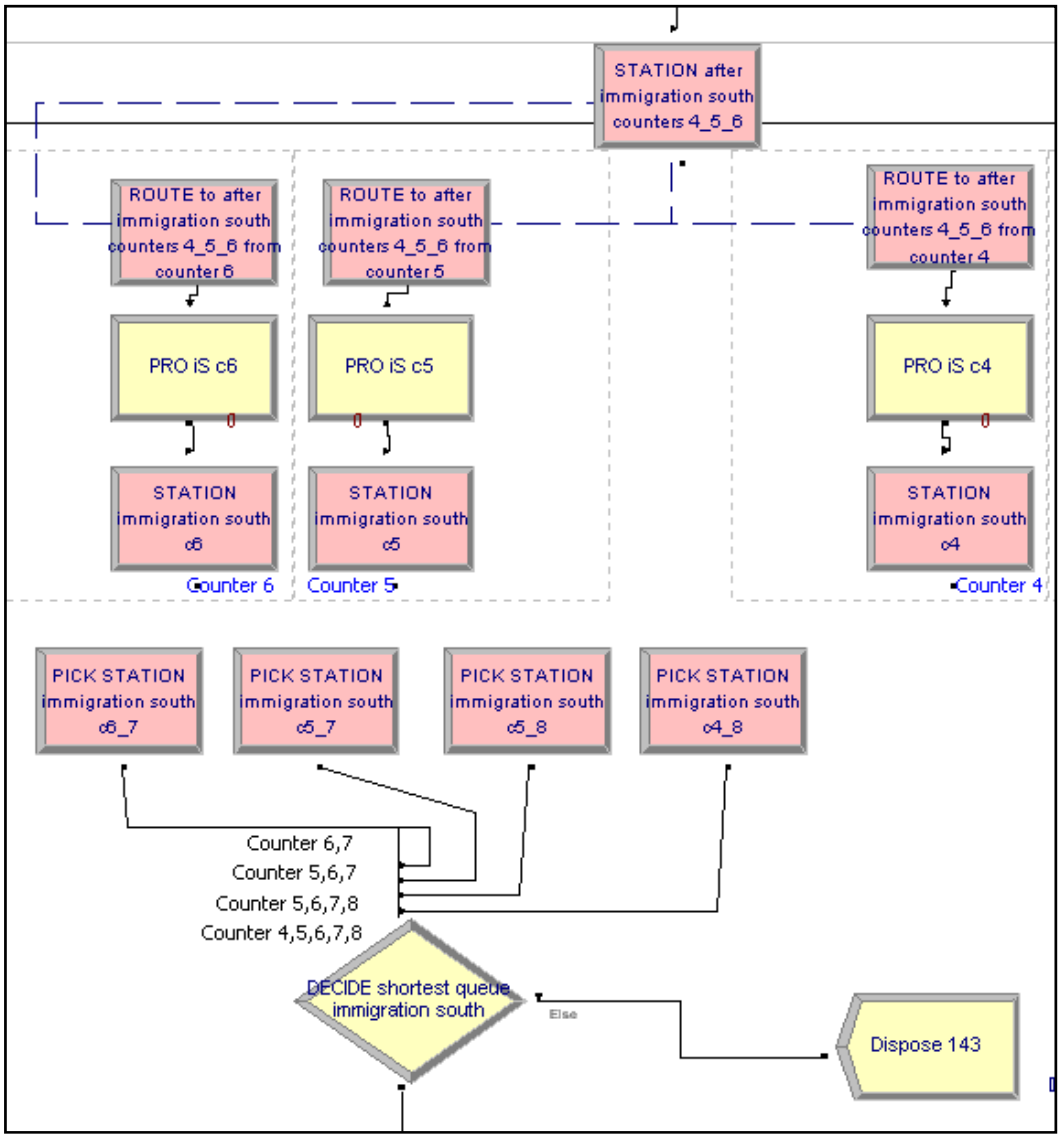

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Figure 4.8: Modeling operations at the immigration counters

4.1.8 Modeling Originating Passengers Activities in the Departure/Transit Hall

It is a complex task to model passengers activities in the departure/ transit hall because each individual's behaviour will determine their activities and actions. To model passengers activities, the dwell time of the passengers is determined first. This is the time which is available to the passengers for activities in the departure/ transit hall. Next, the simulation attempts to model passenger's activities using their activity profile. The simulation model has been developed with the capability to simulate 6 different activities profiles. Each activity profile will dictate the concessionaires they visit and if they take any rest in one of the rest areas in the departure/ transit hall.

a. Determine Dwell Time of Passengers

The model will determine a time duration which passengers spend in the departure/transit hall before going to the gate lounge for boarding. This is done by the model shown in Figure 4.9. This model is used for both the passenger using the immigration counters in the North and South side of Terminal 2.

The "DECIDE long shopping function" module will test the dwell time passengers have before the departure of their flight. If they have less than half an hour, they will be sent to the next DECIDE module which will immediately direct them to either the north gates or the south gates. If they have 30 minutes or more for other activities, the ASSIGN random shopping time modules will assign them with a random shopping time duration. This random shopping time that has been assigned to them are tested

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using the "DECIDE shop time ok" modules to see if it is less than the duration they have before the departure of their flight. If the shopping time assigned to them is more than the duration they have before the departure of their flight, it will be looped back to obtain another random shopping time from the ASSIGN module. To prevent an infinite loop, a maximum number of loops is specified, beyond which the entity will proceed directly to the gate lounge.

Passengers whose dwell time is less than the duration they have before departure will go to the last DECIDE module whereby they are subsequently assigned an activity profile.

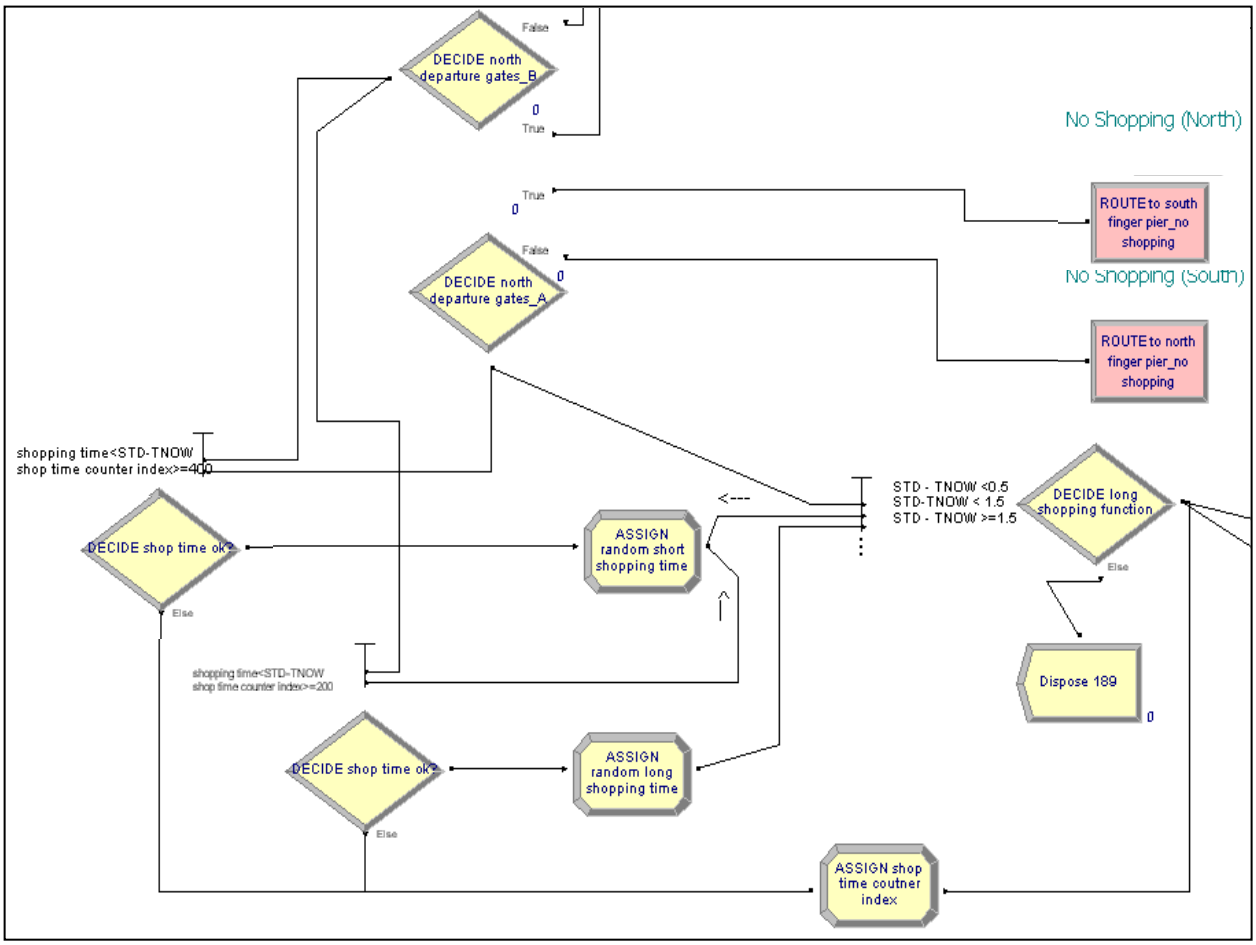

Figure 4.9: Determine dwell time of passengers in departure/ transit hall

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b. Modeling Passenger's Activity Profile

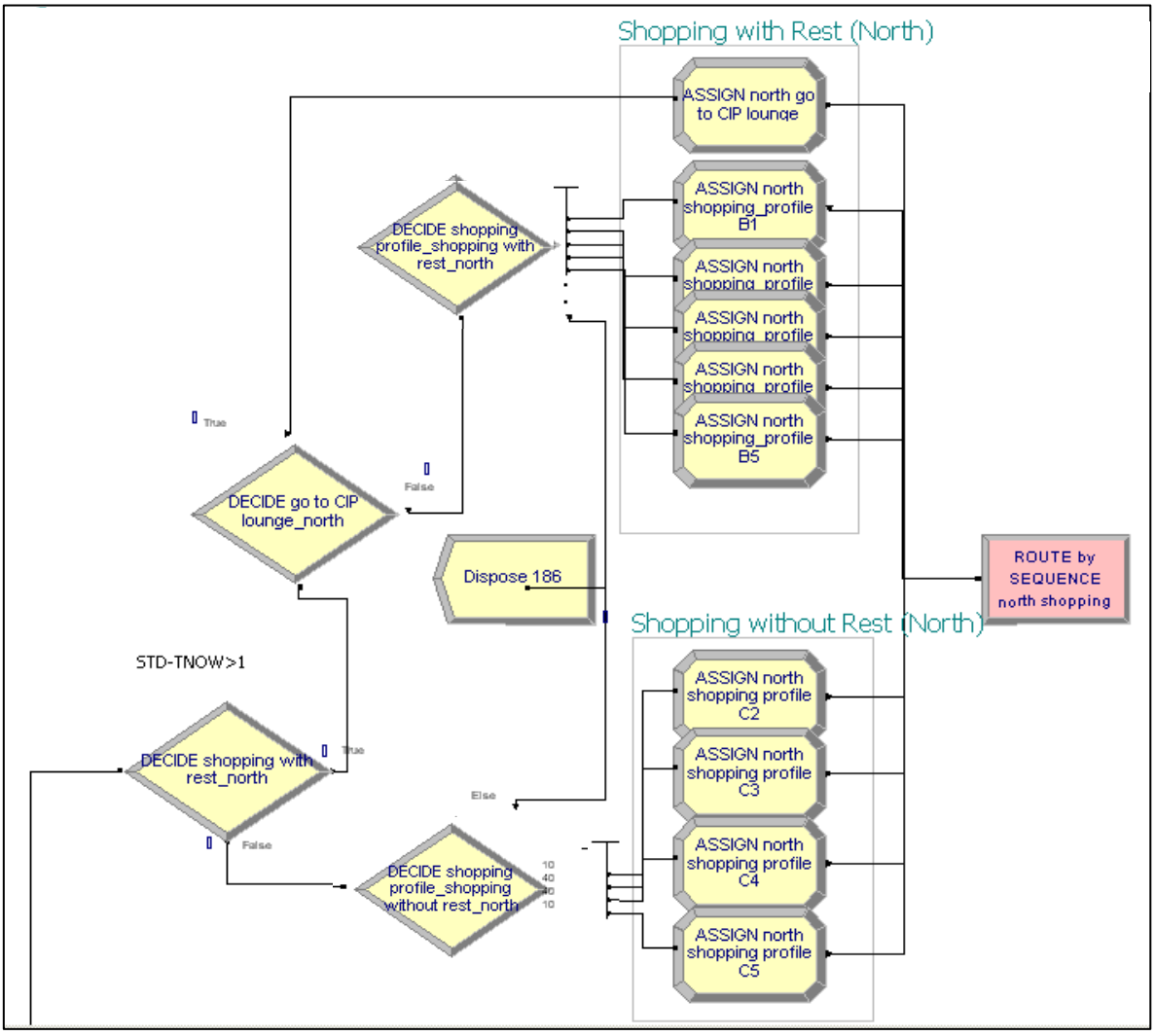

Figure 4.10: Modeling passenger's activity profile.

Figure 4.10 shows how passenger's activity in the departure/ transit hall is modeled. The simulation model was developed to give a passenger one of six characteristic

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profiles, for example a male profile, a female profile etc. Each of these profiles has a corresponding set of shops he/she will visit. This is defined in the SEQUENCE data module. The first DECIDE module uses the shopping time assigned to the passengers to determine the number of shops passengers will visit and if they will rest at one of the rest areas in the departure/transit hall. The subsequent DECIDE and ASSIGN modules determine the shopping profile of passengers. The DECIDE modules splits the passengers into each profile according to a percentage while the ASSIGN modules assigns a profile to the passengers. After that, the ROUTE module will animate passengers moving from one shop (i.e. STATION module) to another as specified from the entries in the SEQUENCE data module. The route time between each station is the dwell time divided by the number of segments. The number of segments is the number of times a passengers walk from a point to another. For example, a passenger walking from the immigration counter to the fashion apparel shop, then to the book shop and finally the jewelry shop will be considered to have 3 segments (Figure 4.11).

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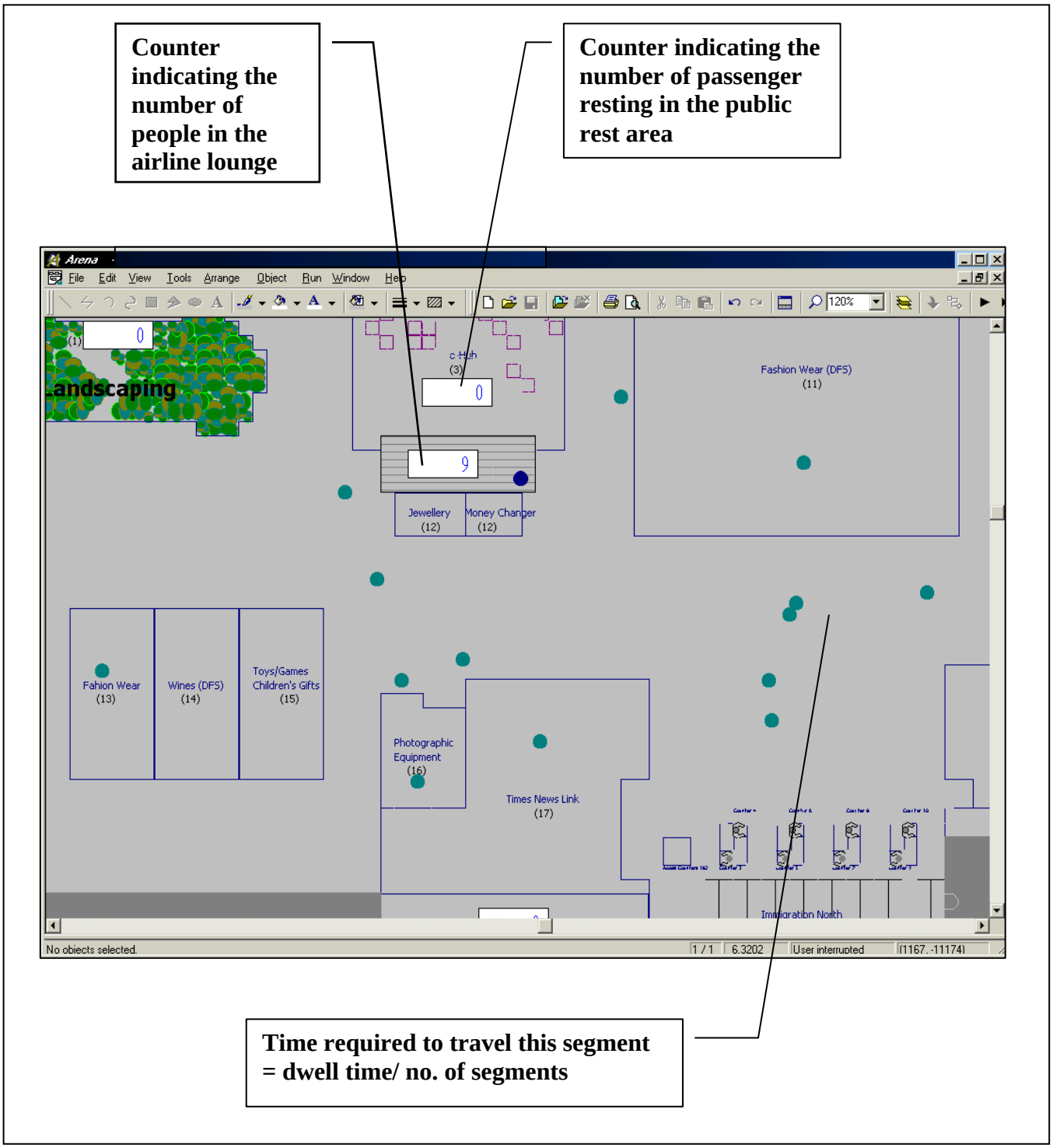

Figure 4.11: Animation of passengers in the departure/ transit hall

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Passengers whose dwell time is more than 1 hour are assumed to rest at one of the rest area in the departure/transit hall as part of his/her activity. Figure 4.12 shows how this is modeled. The PROCESS module models passengers resting by delaying them for a duration which is a multiple of the segment time. Next, the ROUTE module route them to their next station. The STORE and UNSTORE modules increment the counter when a passengers enters the rest area and decrease the counter when passengers leave the rest area respectively. Figure 4.13 is an overview of the north section of the departure/transit hall showing the immigration counter at the bottom of the screen, the shops and the rest area at the top of the screen.

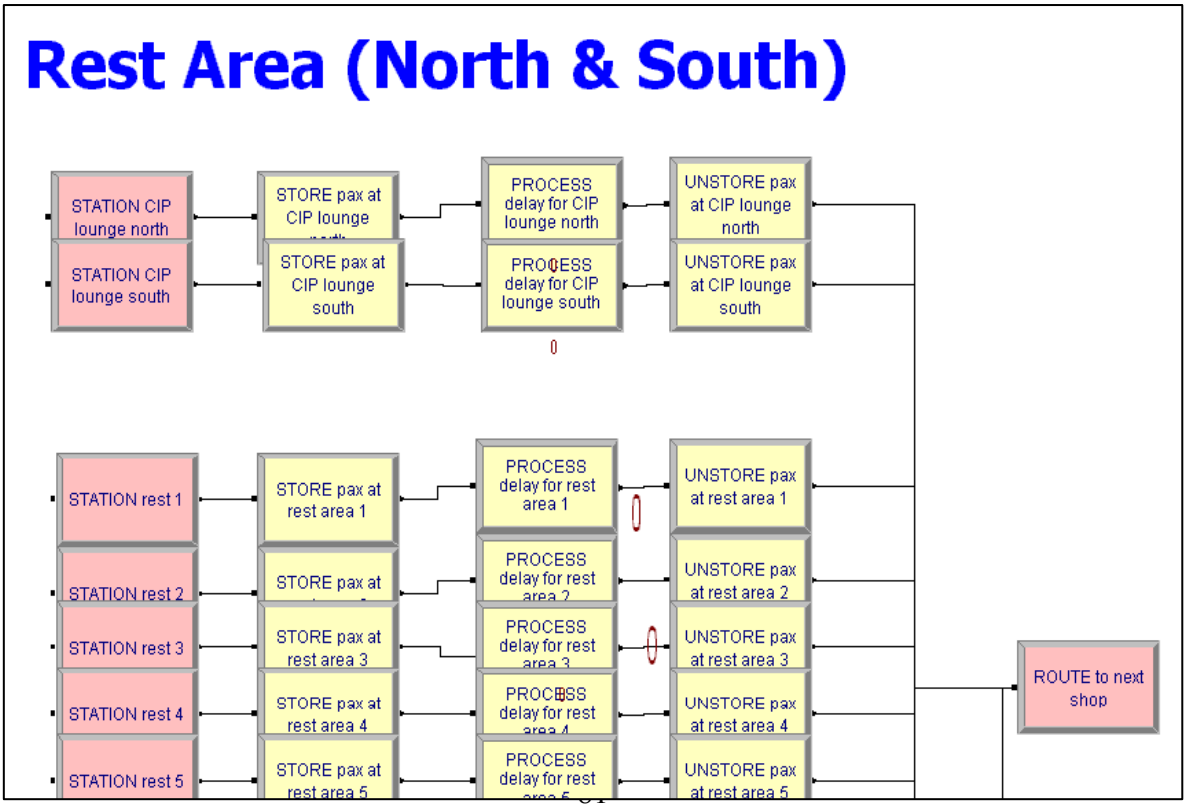

Figure 4.12: Modeling passengers usage of the rest areas

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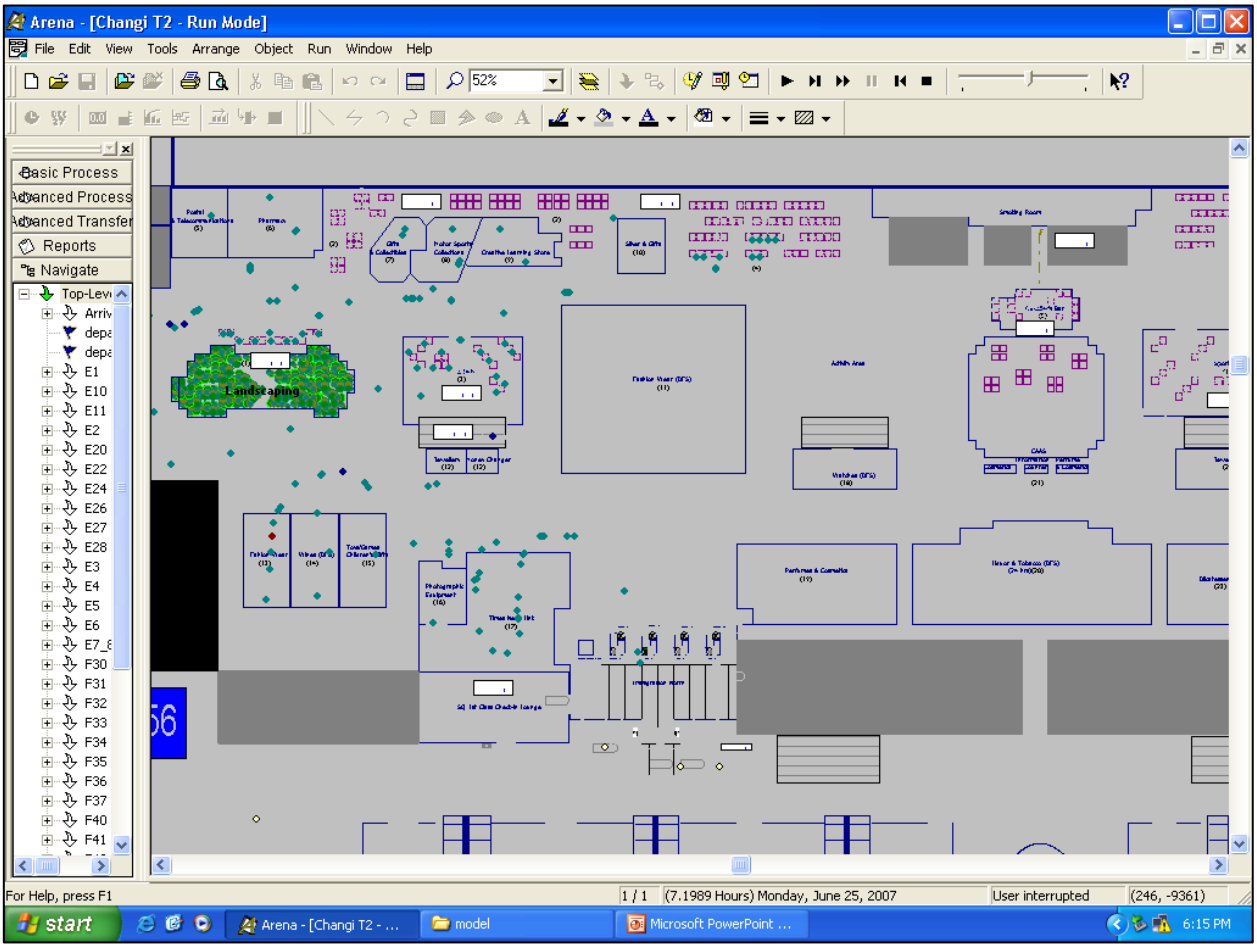

Figure 4.13: Overview of departure/transit hall (north)

4.1.9 Modeling Passenger's Walking Speed

The last entry in the SEQUENCE data module that specifies passenger's shop preference is a point near the start of all the north gates or a point near the start of all

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the south gates. All passengers are routed to either point and from there a set of DECIDE and ROUTE modules will determine the departure gate of the passenger and animate them walking to the gate (Figure 4.14). The walking time to the same gate is different for each passenger. As such, the route time for the passengers is modeled as a triangular distribution with its minimum value equals to the average time a passengers will take if he/she uses the travelator and walk on it at the same time. The mode is specified as the average time a passenger will take if he/she walks to the gate without the use of a travelator. The maximum value is set as the time which a passenger will take if he/she uses the travelator but is stationary when he/she is on it. Passenger can enter the gate lounge only if it is open.

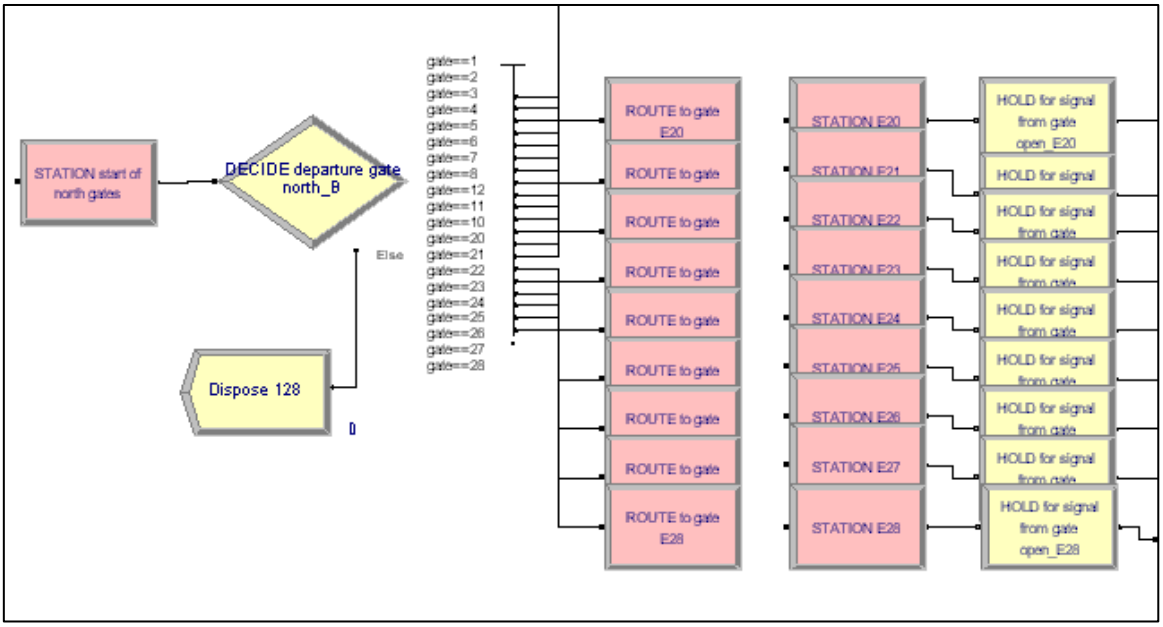

Figure 4.14: Modeling passengers walking speed

The HOLD module will simulate passengers waiting outside the gate lounge until a signal which signifies the that the gate lounge is open is transmitted to it by the SIGNAL module in the gate lounge sub-model in Section 4.1.10a.

4.1.10 Modeling Operations in the Gate Lounge

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Once the gate lounge is opened, the PROCESS module models the process of two airport auxiliary police checking the boarding pass and passport of the passengers.

Upon entering the gate lounge, passengers will place their bags through the x-ray machines while they walk through the metal detector. If the metal detector indicates that the passenger is carrying a prohibited item, he or she will be subjected to a secondary screening which is a 'sweep' with a handheld metal detector before he is allowed to collect his bag. If the x-ray operator suspects that the bag contains prohibited items, the passengers will be asked to open the bag for a visual inspection. After completing these security checks, the passengers will proceed to the gate editing counter where their names are added to the flight manifest. They will then wait inside the gate lounge until the aircraft is ready for boarding. The animation for gate lounge E2 is shown in Figure 4.15.

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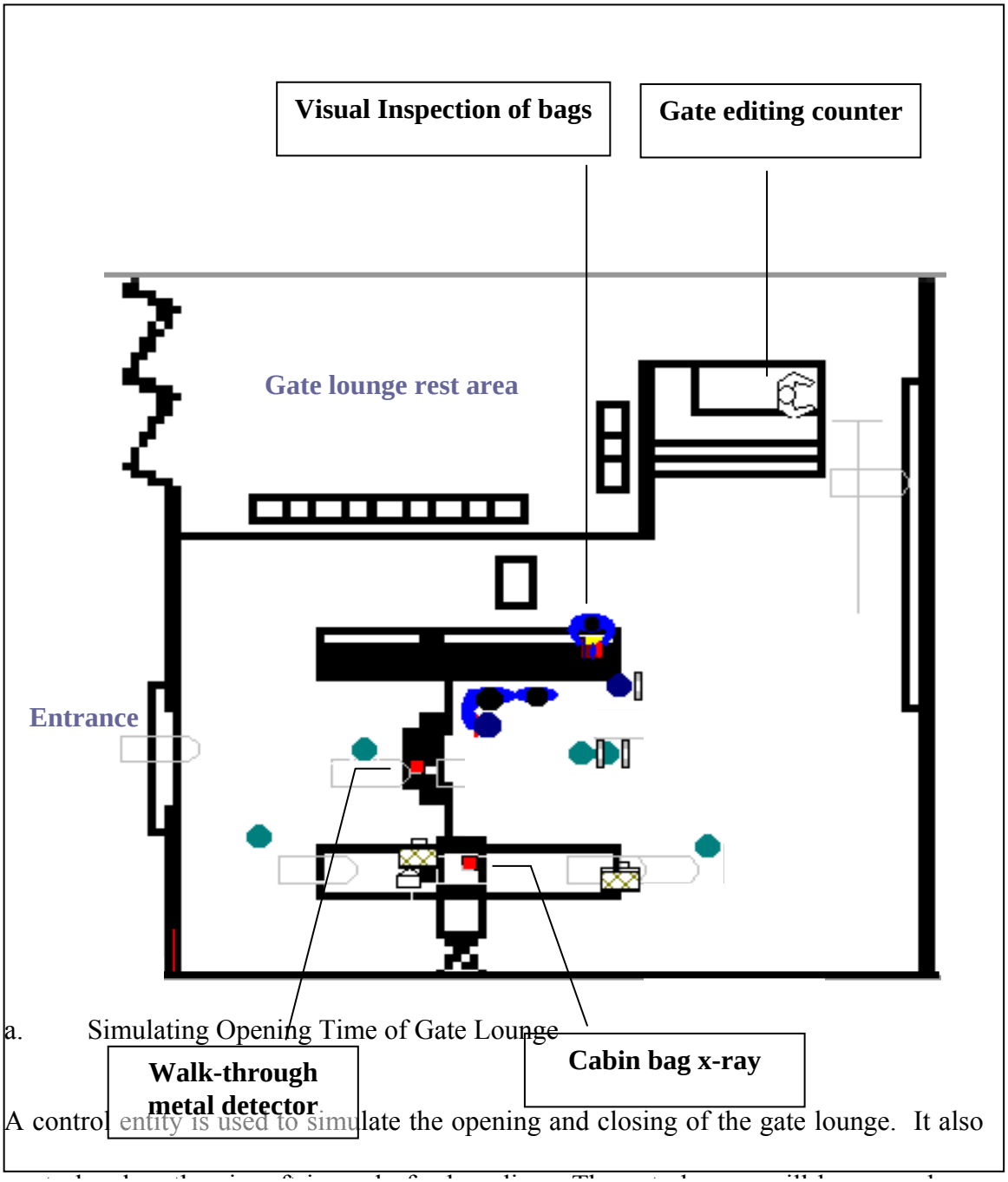

a. Simulating Opening Time of Gate Lounge

A control entity is used to simulate the opening and closing of the gate lounge. It also

Figure 4.15: Animation of gate lounge E2

hour before the scheduled departure time of the flight (Appendix A). Figure 4.16 illustrates how this is done. A control entity is created at the start of the simulation. The READ module will read the departure time of the flight leaving from that particular gate. Next, the DELAY module holds the control entity until the simulation

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clock advances one hour before the departure time. The first SEPARATE module duplicates the control entity. It sends a control entity back to read the next departure time from the READ module while another control entity is duplicated again by the second SEPARATE module. The original entity will control the gate opening time while the duplicated entity will control the boarding time of the passengers.

The original control entity will go to the SIGNAL module whereby it will transmit a signal to the HOLD entity mentioned in the previous section. This will release the passengers from the HOLD module and allow them to continue to the next module. After this, the DECIDE module will determine if the gate should remain open by comparing the current simulation time (TNOW) and the departure time of the flight. If the current simulation time is smaller than the departure time of the flight, the control entity will be looped back to the SIGNAL module. However, before it arrives at the SIGNAL module, it must go through a DELAY module first. This DELAY module serves to advance the simulation clock by delaying the entity by 60 seconds. This also means that the condition for the opening of the gate is evaluated every minute. This set of SIGNAL and DELAY modules ensure that a signal is sent every 60 seconds when the gate is open. The duplicated control entity which controls the boarding time works the same way as the original entity which controls the gate opening time.

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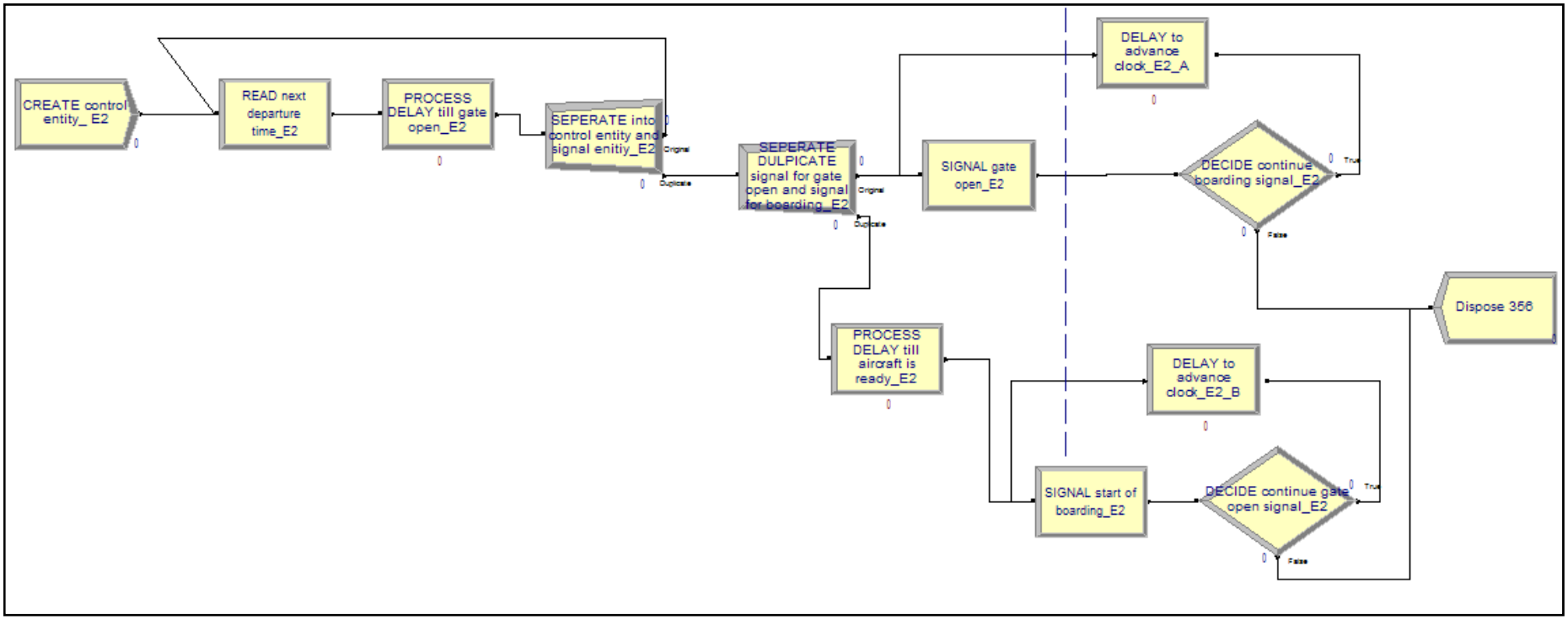

Figure 4.16: Simulating gate lounge opening time and passengers boarding time using a control entity

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b. Modeling Security Screening at Gate Lounge

Once the passenger entity enters the sub-model, the ASSIGN module will assign it a variable called IDENT. IDENT is an ARENA variable which returns the value *Entity Number*. This is a unique number given to the entity as a record of its existence. Since the *Entity Number* of each entity is unique, it will be used to match passengers with his/her bags after the x-ray. The ROUTE module will animate passengers placing their cabin bags at the start of the convey belt which leads to the x-ray machine. Next, the DECIDE module will split passengers with 2 cabin bags and 1 cabin bag based on a specified percentage (Appendix A). Passengers with 2 cabin bags will be assigned an attribute using the ASSIGN module. This will be used later in the model to ensure that passengers has collected all their bags from the x-ray machine. The SEPARATE module then duplicates the passengers by the number of cabin bags he/she is carrying. The duplicated entity is then re-assigned as a bag entity and given a picture of a bag by the ASSIGN modules. From this point on, the original entity continues through the simulation as passengers while the duplicated entity continues down the model as bags until they are matched at the end of the x-ray machine (Figure 4.17).

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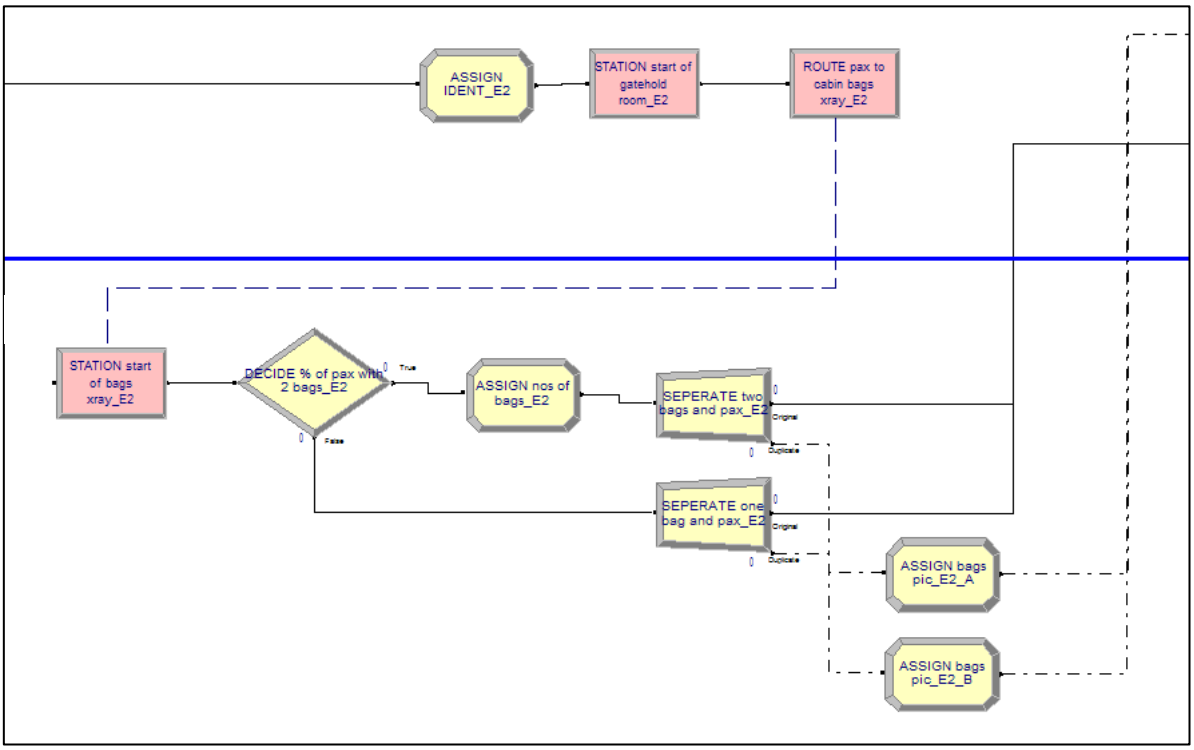

Figure 4.17: Separating cabin bags and passengers in the gate lounge

in module route passengers to the walk-through metal detector where they undergo a metal detection test which is modeled by yet another PROCESS module. The DECIDE module is used to specify a percentage of passengers who will pass the metal detection test (Appendix A). Passengers who pass the test are immediately routed to the end of the x-ray machine to collect their bags while passengers who fail the metal detector test are routed to another station to be "swept" using a handheld metal detector. Once they are found to be free from prohibited items, they will also be routed to the end of the x-ray machine to collect their bags (Figure 4.18).

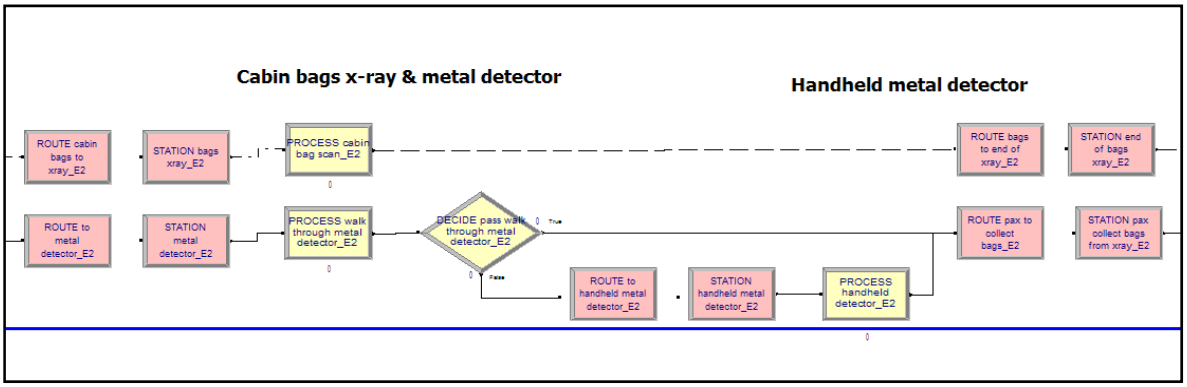

Figure 4.18: Cabin bags x-ray and metal detector

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The passengers and their respective cabin bags will be reconciled using the MATCH module (Figure 4.19). The MATCH module will match the passengers with their bags according to their IDENT which has been assigned at the beginning of this sub-model. Before they are matched, the passengers and bags are held in separate queues. Once they are matched, they will move off together from two different exit points. The bags entities will be disposed off since passengers has already collected their bags. From this point on, the only entity simulated will be the passengers. Since the MATCH module can only match one passenger to one bag at a time, a DECIDE module is used to test the number of bags a passenger has and loop passengers with two bags back to the MATCH module. Passengers with two bags will be assigned a picture of a bag so as to indicate that he/she is still waiting for his/her second bag. After passengers have collected their bags, the DECIDE module will specify a percentage of passengers whose bags fail the x-ray inspection and need to be opened for visual inspection. The ROUTE module will animate these passengers moving to a counter where the visual inspection is modeled by the PROCESS module. Like the other passengers whose bag pass the x-ray inspection, the last ROUTE module will model these passengers proceeding to the gate editing counter after their bags pass the visual inspection.

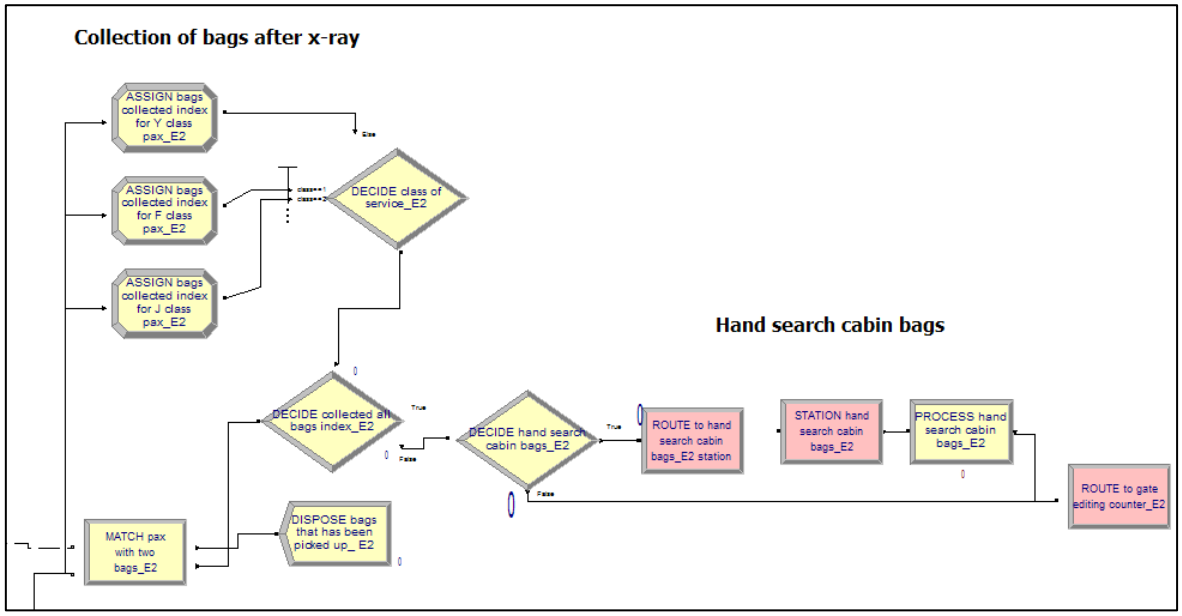

Figure 4.19: Matching cabin bags to passengers

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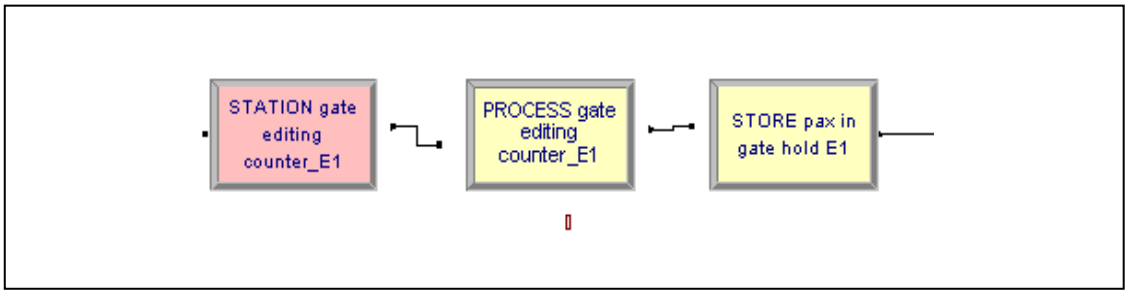
c. Modeling Operations at the Gate Editing Counter

Figure 4.20 shows the simulation logic behind the gate editing counter. At the gate editing counter, passenger's boarding pass is retained and the stub returned to them. At this time, the passenger's name will be added to the flight manifest (Appendix A). This is modeled using the PROCESS module. Next, passengers will stay in the gate lounge until the aircraft is ready for boarding. This is not animated in the simulation model, but is modeled as a storage. A STORE module will count the number of passengers inside the gate lounge. The number of passengers per unit area is the criteria to determine the capacity of the lounge (Appendix A).



d. Figure 4.20: Modeling operations at the gate editing counter

When the aircraft is ready for boarding, the ground handling agent will first invite passengers with young children and elderly passengers to board (Appendix A). Next, First and Business Class passengers will board the aircraft followed by Economy Class passengers. Figure 4.21 shows how this is simulated in ARENA. The first DECIDE module specifies the percentage of passengers with special needs. These passengers entities will then proceed to the HOLD module to wait for a signal from the SIGNAL

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module mentioned in section 4.1.10a. The rest of the passengers entities will go to the DECIDE module whereby they will be separated into First, Business or Economy Class. These two groups of passengers will also be held by different HOLD modules. The HOLD module for priority boarding continuously scans for the queue condition of the other HOLD module which holds back passengers with special needs. Once there are no entities in that queue, it will release the entities for boarding. The other HOLD module which holds back Economy Class passengers will in turn scan the queue condition for both the HOLD modules that holds back First or Business Class passengers and passengers with special needs. This cascaded group of HOLD modules ensures that all passengers with special needs board the aircraft first, followed by First and Business Class passengers and lastly Economy Class passengers.

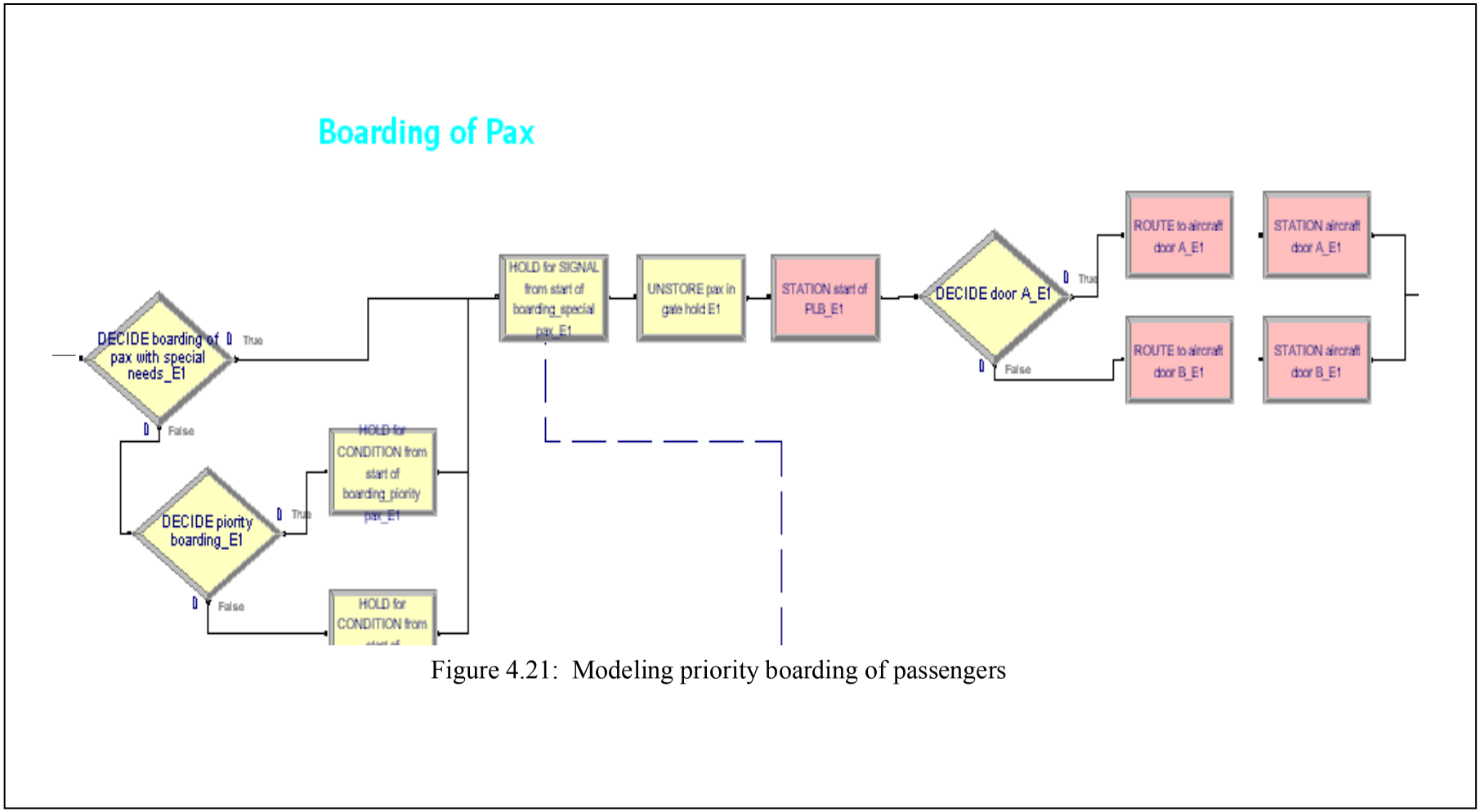

Figure 4.21: Modeling priority boarding of passengers

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Lastly, the DECIDE and ROUTE modules will animate First or Business Class passengers going to the aircraft's first door (i.e. Door A) while Economy Class passengers go to the second door (i.e. Door B). The passenger entities then exit the sub-model and is subsequently disposed off the model as they enter the aircraft.

4.2 Modeling Transfer and Terminating Passengers

Transfer passengers are travelers who come to Singapore to connect to another flight while terminating passengers are travelers who are ending their journey in Singapore. This section describes in detail how terminating and transfer passengers are modeled using ARENA.

4.2.1 Import Arrival Flight Schedule and Passengers Attribute

Figure 4.22 shows the method which flight schedule and passengers' attributes are imported from an external file. These attributes that are assigned to the passengers will be used in other parts of the model as well. A control entity is created at the start of the simulation (i.e. simulation time 0.00). This control entity will read the arrival time of the next flight using the READ module. The DELAY module then delays the control entity until the simulation clock advances to the actual arrival time of the flight. After that, the control entity will read the arrival gate of the flight. The SEPARATE module duplicates the control entity so that one of them will read the set of attributes of transfer passengers while the other will read the attributes of terminating passengers. Terminating passengers' attributes include information like the number of terminating passengers and the baggage claim belt number. This module will also duplicate the control entity by the number specified in the external file which the "READ no of terminating pax" module reads from. These duplicates will now be modeled as

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terminating passengers. Similarly, the control entity reads the number of transfer passengers, their connecting flight and the departure gate of the connecting flight. The SEPARATE module sends one control entity to read the next arrival flight and at the same time duplicates the control entity by the number specified in the external file which the "READ no of transfer pax" module reads from. These duplicates will now be modeled as transfer passengers. The three sets of READ modules enable the user to simulate up to three connecting flights from one arrival aircraft.

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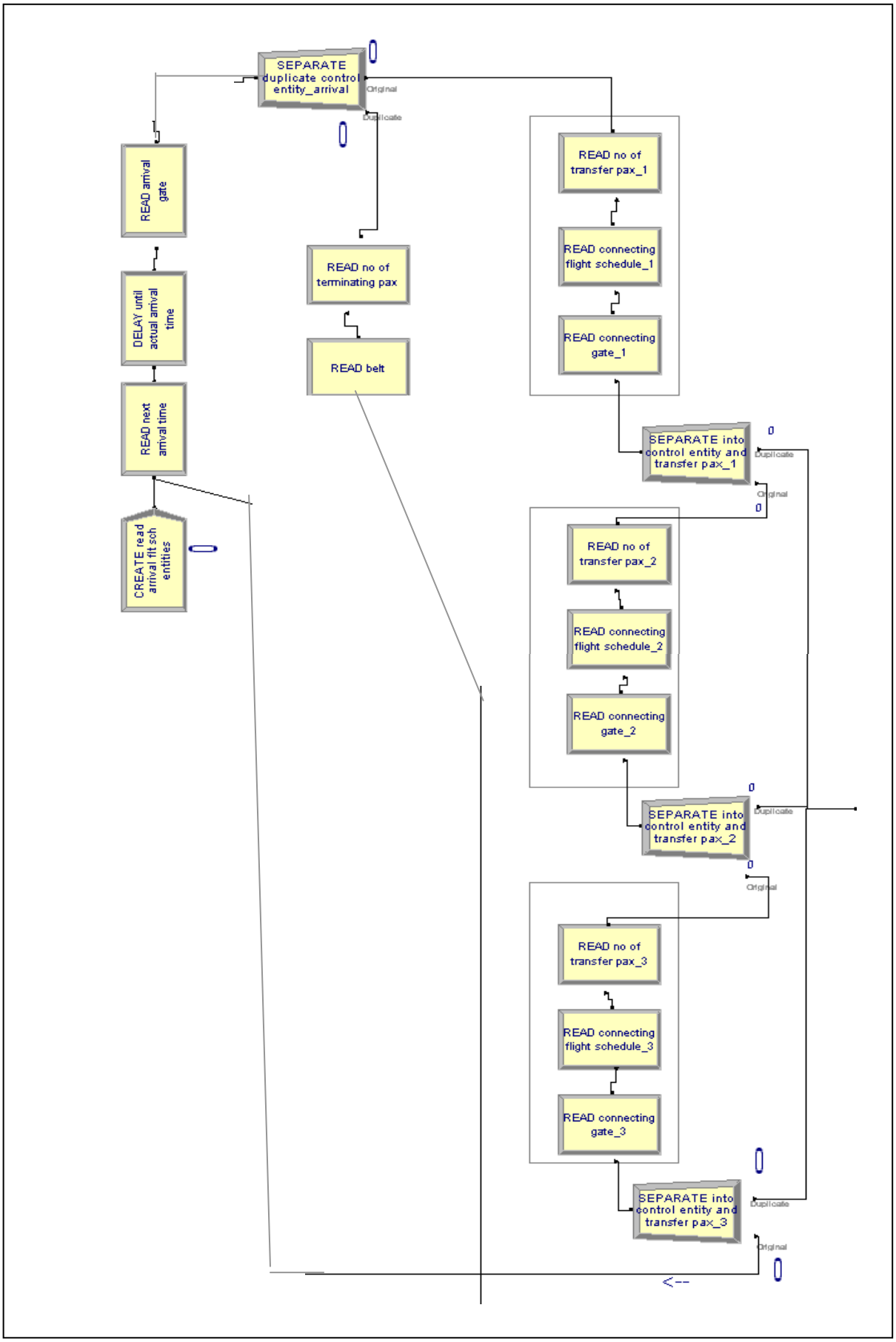

Figure 4.22: Importing arrival flight schedule and passengers attribute

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4.2.2 Modeling Terminating and Transfer Passengers Deplaning

The two ASSIGN modules in Figure 4.23 will assign an attribute to the terminating and transfer passengers so that they can be easily identified later. The DECIDE module will separate these passengers into First, Business or Economy Class according to a percentage specified. The next set of ASSIGN modules then assign different colours to the 3 classes of passengers so that they could be easily differentiated in later parts of the model and easily identified in the animation. The other set of DECIDE and ASSIGN modules perform the same function on the terminating passengers which has a different colour code. This is followed by a DECIDE module that models passengers arriving from the north or south portion of the terminal. The next set of DECIDE, STATION and ROUTE modules model passengers arriving at a particular gate in the north or south portion of the terminal and animate them moving to the departure/transit hall.

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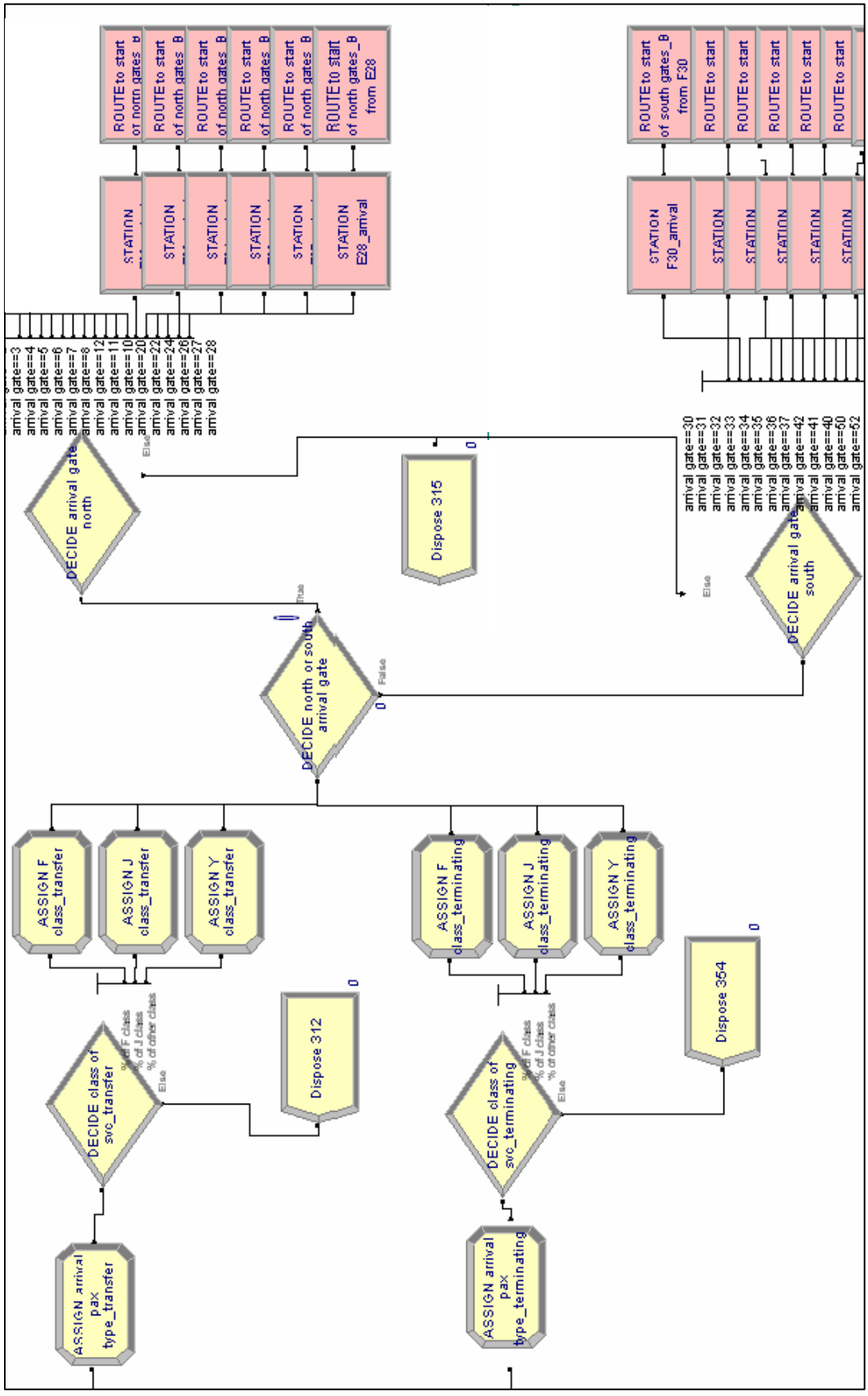

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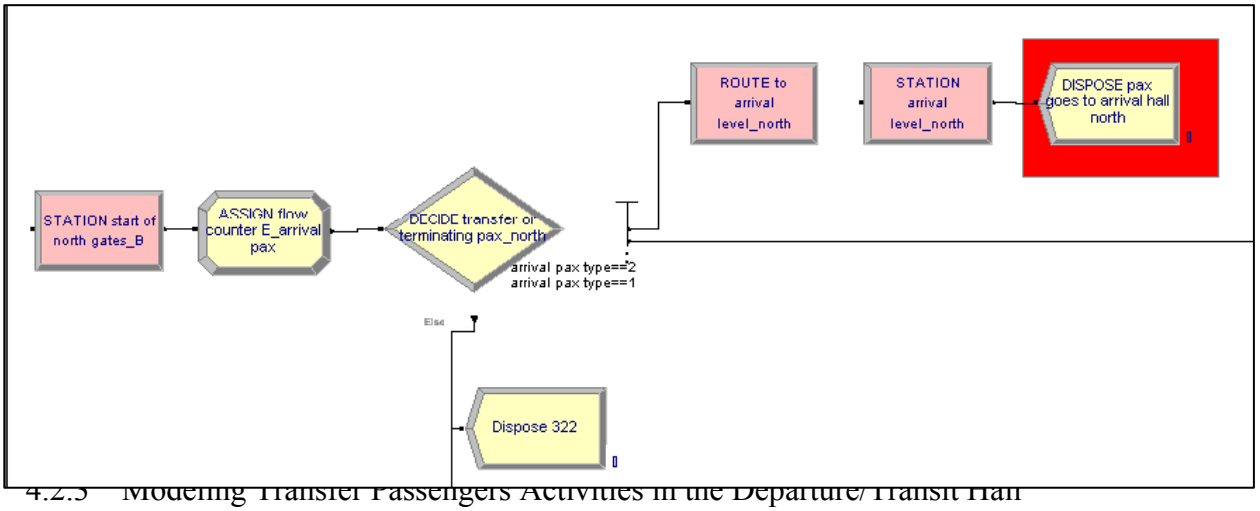
The STATION module in Figure 4.24 corresponds to a point in the departure/transit lounge. Passengers will be transferred to this point by the ROUTE module in the previous section. The ASSIGN module then increases the number on a flow counter. This is for the purpose of measuring the level of congestion along the flow corridor of the terminal. Next, the DECIDE module will split these passengers into transfer or terminating passengers based on their attribute. Terminating passengers will be routed to the arrival hall using the ROUTE module while transfer passengers will be assigned an activity profile.



4.2.3 Modeling Transfer Passengers Activities in the Departure/ Transit Hall

Figure 4.24: Identifying terminating and transfer passengers

The logic behind modeling transfer passengers in the departure/transit hall is exactly the same as that of originating passengers who are in the departure/ transit hall. Passengers will be assigned a random dwell time based on the departure time of their connecting flight. Their activity profile is modeled in the same way as those of originating passengers in Section 4.1.8b. Once they have completed their sequence of activities, these passengers will be routed to their departure gate.

4.3 Modeling Well-Wishers

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Well-wishers are members of the public who go to the airport to see passengers off. This chapter describes in detail how well-wishers are modeled using ARENA. Well-wishers will enter the airport's departure hall from the car park, the bus station, or the train station (Appendix A). They will meet originating passengers near the respective check-in counters. Next, they will accompany these originating passengers until they leave the area accessible to the public and enter the departure/transit hall. Well-wishers will then leave the airport terminal via the car park, by public bus or train. This section describes in detail well-wishers are modeled using ARENA.

4.3.1 Import Well-Wisher's Attribute

Figure 4.25 shows the method which well-wishers' attributes are imported. A control entity is created at the start of the simulation. This control entity will be held by the HOLD module until the first originating passenger enters the model. When the first originating passenger enters the model, a signal from the SIGNAL module in section 4.1.1 will be sent to release the control entity to the two READ modules.

The first READ module will read the number of well-wishers accompanying the passengers from the file "well wishers.txt". Since well-wishers will meet the passengers at the dwell space near their check-in counter, the second READ module is required to read the check-in row of the passengers and assign it as an attribute of the well-wisher. This will enable well-wishers to go to the correct dwell space near the check-in row.

Next, the SEPARATE module will send the control entity back to hold for a signal from the passenger on the next flight. It will also duplicate itself according to the

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number of well-wishers as read from the file "well wishers.txt". These duplicates will be modeled as well-wishers.

Finally, Using the DELAY module, well-wishers will be delayed in the same profile as the passengers. This will model the well-wishers arriving at the airport at different time and in proportion to the number of originating passengers.

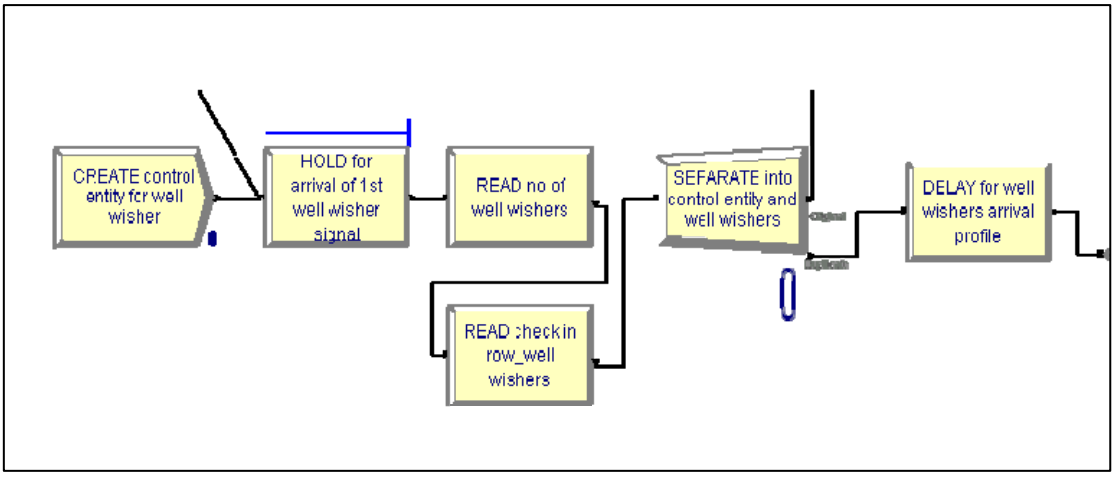

Figure 4.25: Importing well-wishers' attributes

4.3.2 Modeling Well-Wisher's Split for Different Ground Access Modes

Figure 4.26 shows how well-wishers choose a mode of transport to the airport and how they are routed to their respective dwell space near the check-in counters. Well-wishers enter the airport from the MRT station, bus terminal or car park, as specified in the DECIDE module. The next DECIDE and ROUTE module will route well-wishers to their respective dwell space near the check-in row according to the well-wishers' attribute which has been assigned with the READ module mentioned in the previous section.

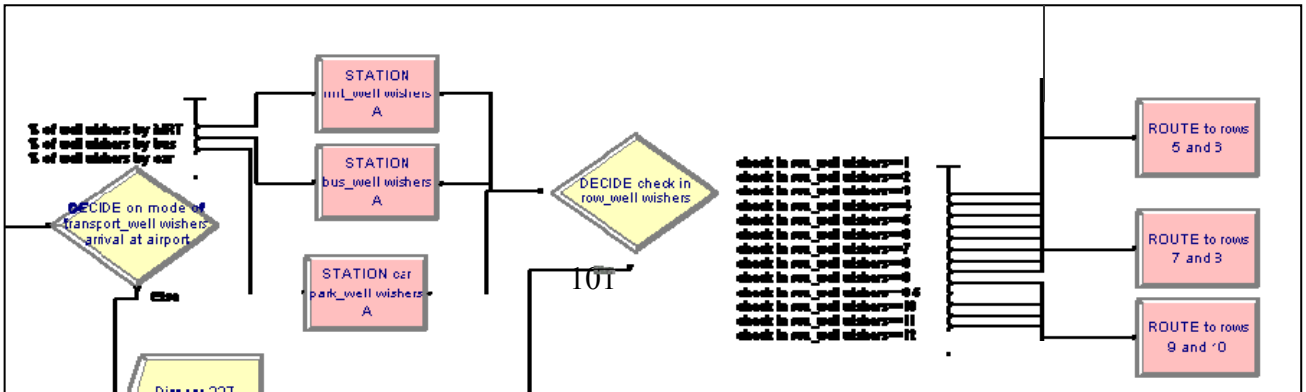

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Figure 4.26: Modeling well-wisher's split between different modes of ground access

4.3.3 Modeling Well-Wishers' Activities in the Check-in Hall

After well-wishers reach the dwell space near the check-in row, they are simulated to stay around that area while passengers go through check-in formalities. Figure 4.27 showed how this is modeled with the use of a DELAY module. In order to model well-wishers "accompanying" passengers, the delay probability distribution is specified as the probability distribution for passengers' check-in processing time. This will ensure that the number of passengers leaving the check-in counters is proportional to the number of well-wishers leaving the dwell space.

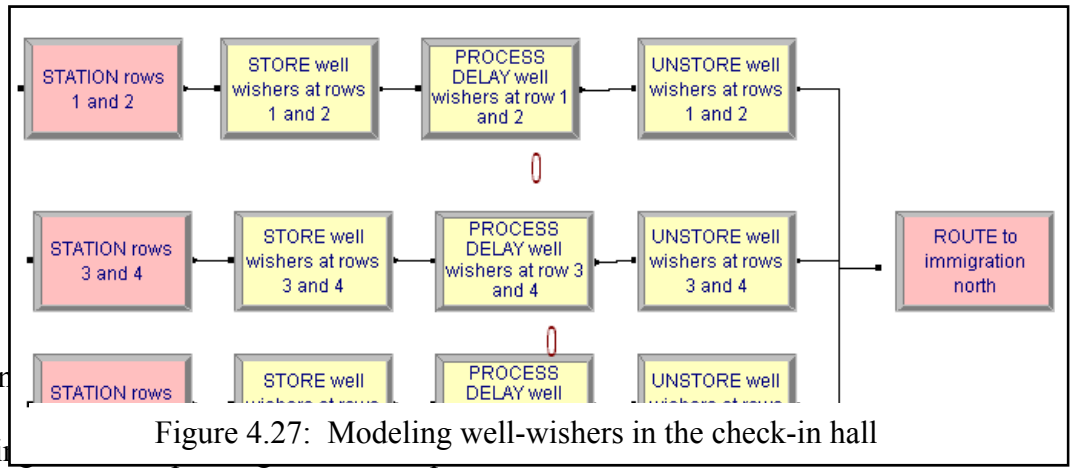

Figure 4.27: Modeling well-wishers in the check-in hall

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UNSTORE modules will increase a storage counter when a passenger enters the dwell space and decrease the storage counter when a passenger leaves the dwell space. The animation showing the check-in counters, dwell space near the check-in counters and

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the storage counter are shown in Figure 4.28. After the delay, the ROUTE module will route well-wishers to the dwell space near the police check-point.

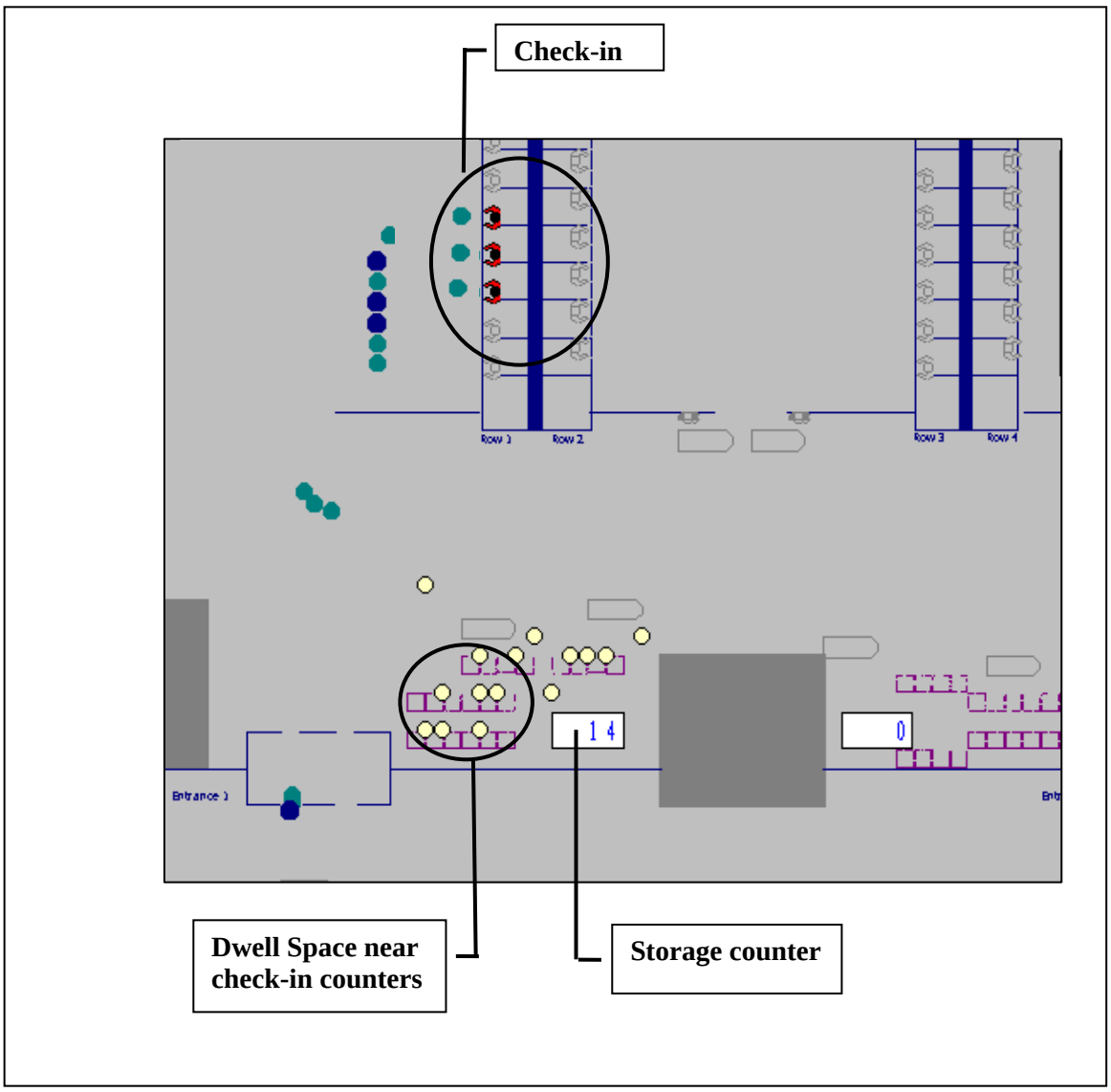

Figure 4.28: Animation of dwell space in the check-in hall

4.3.4 Modeling Well-Wishers Leaving the Airport

After passengers has completed check-in formalities, well-wishers will accompany them to the police check-point which separates the area of the airport that is open for public access and the area that is only accessible to passengers. Figure 4.29 shows how well-wishers are modeled at the dwell space at the police check-point before leaving the

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airport. This is very similar to the simulation logic at the check-in dwell space. After well-wishers reach the dwell space near the police check-point, they will undergo a delay. This is to model them bidding farewell to the passengers before they enter the departure/transit hall. The STORE and UNSTORE modules control the storage counter which indicates the number of people at the dwell space. After the delay process, the DECIDE and ROUTE modules are used to model passengers leaving the airport via the train station, bus terminal or car park.

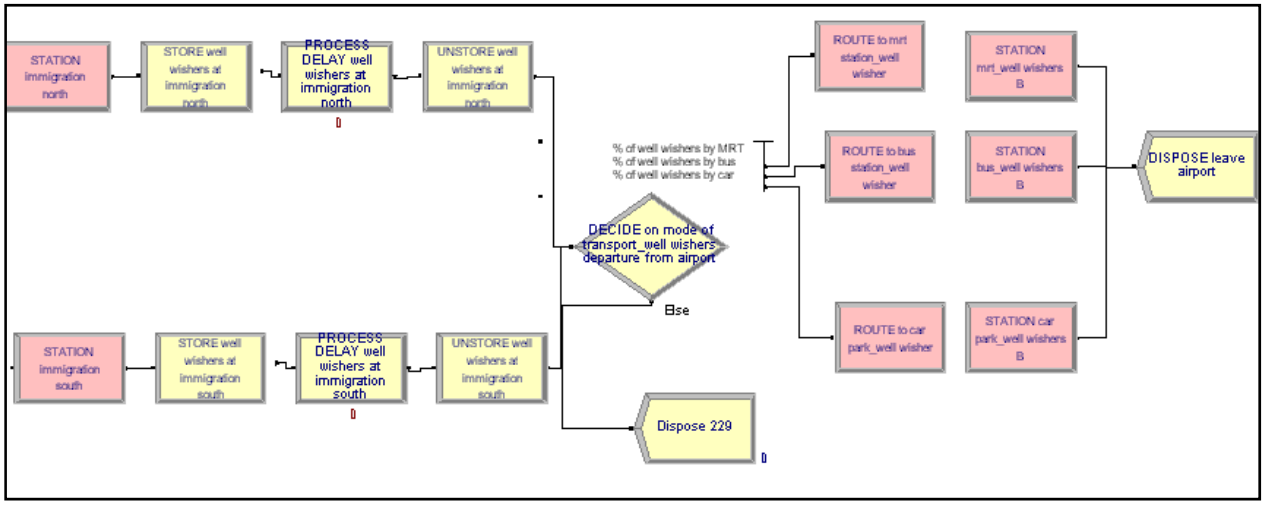

Fig 4.29: Modeling well-wishers at the dwell space near the police check-point and leaving the airport

4.4 Model Verification and Validation

Model verification refers to the task of ensuring that the model behaves as intended and there are no bugs in the simulation model. The simulation was run and the animation was closely observed to see if the model behaves as expected. For example, the animation confirmed that passengers that failed primary security screening at the gate lounge went for secondary screening. Model validation refers to the task of ensuring

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that the model behaves in the same way as the actual system would under the same conditions. The output of the simulation such as maximum queue length and maximum waiting time could be compared with actual survey data carried out by survey companies engaged by the Civil Aviation Authority of Singapore (Appendix A). However, model validation could not be carried out because the Civil Aviation Authority of Singapore could not reveal survey data due to confidentiality reasons (Appendix A). In lieu of actual survey data, the Head of Terminal 2 Operations was asked to watch the animation. He confirmed that it resembles what is observed on the ground (Appendix A).

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CHAPTER 5

SIMULATION EXPERIMENT & RESULTS

The simulation model had been developed in the previous chapter and simulation experiment is ready to be carried out. Two scenario analysis and one sensitivity analysis would be carried out using Singapore Changi Airport Terminal 2 as a case study. Simulation experiment would be designed and input variables and data would be entered into the simulation model.

5.1 Scenario Analysis: Scenario 1- Peak Hour Analysis

Analyzing the peak hour operations of an airport would enable airport planners to determine if the airport landside capacity is sufficient. When capacity is sufficient to meet peak hour demand, it follows that it would be sufficient to meet the demand at all other times.

5.1.1 Design of Experiment

The peak hour for Changi Airport Terminal 2 is between 0900 hours to 0959 hours with 13 departure flights (Appendix A). Check-in counters would be opened 3 hours before departure. This means that passengers for the peak hour departure flights would check-in between 0600 hours and would use the airport facilities until the last flight of the peak hour which departs at 0959 hours. The landside capacity during these hours would be of interest in this analysis because this is when the demand for airport landside capacity is at its peak.

A steady state system is a system whereby the starting condition of the simulation is not zero. In the domain of airport landside capacity planning, it means that there are

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already passengers in the airport and resources are already occupied. A warm up period of 6 hours is used to ensure that the simulation model is in steady state. The rationale is that approximately 75% of transfer passengers has a transfer dwell time of less than 6 hours (Appendix A). No simulation data would be collected during this warm up period.

A terminating condition is the state of the simulation whereby the simulation will be stopped. In this analysis, the terminating condition is when the simulation clock is at 0959 hours. This corresponds to the time when the last flight of the peak period departs.

5.1.2 Input Data

As the scope of this thesis does not include the development of the database management sub-system of the DSS, input data such as flight schedule, processing time probability distribution, check-in row assignment had to be input through ARENA. This can be done with the aid of a Microsoft® Excel spreadsheet and the details of this method can be found in Appendix C. However, the following are some input data that requires further explanation.

a. Arrival Flight Schedule

The arrival flight schedule from 0000 hours to 0959 hours with the number of transfer passengers onboard need to be input into the simulation model. Since 75% of transfer passengers will depart within the next 6 hours (Appendix A), they will add on to the demand for airport landside facilities between 0600 hours and 0959 hours which is the focus of this analysis.

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b. Departure Flight Schedule

Although the peak hour departure flights are from 0900 hours to 0959 hours and the focus of the simulation is between 0600 hours to 0959 hours, the departure flight schedule that need to be entered into ARENA is from 0600 hours to 1300 hours. This is because check-in counters are opened from 3 hours before flight departure to 40 minutes before flight departure and originating passengers on flights from 0600 hours to 1300 hours will place a demand on airport landside facilities during the duration of this analysis i.e. 0600 hours to 0959 hours.

c. Passenger Arrival Profile

The passenger arrival profile shows the time passengers arrive at the airport before the departure time of the aircraft. Table 5.1 is the passenger arrival profile used for this simulation experiment (Appendix A). The table shows the probability of passengers arriving at the airport from 180 minutes before the Scheduled Time of Departure (STD). The continuous empirical distribution is used to incorporate actual data directly into the model. This is chosen over a theoretical distribution because there is no theoretical distribution that fits the data below.

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X = Current Time – Scheduled Time of Departure		**Probability**	**Cumulative Probability**
X= a	**X= b**	**P(a < X < b)**	**F(*x*) = P(X ≤ x)**
-180	-165	0.01	0.01
-165	-150	0.01	0.02
-150	-135	0.11	0.13
-135	-120	0.12	0.25
-120	-105	0.15	0.40
-105	-90	0.20	0.60
-90	-75	0.18	0.78
-75	-60	0.12	0.90
-60	-45	0.08	0.98
-45	-30	0.02	1.00

Table 5.1: Passenger arrival profile (Courtesy of CAAS)

d. Passenger Activity Profile

Interview with the Duty Free Shop commercial manager was carried out and Table 5.2 below shows the activity profile of passengers in the departure/transit hall (Appendix A). The activity profile characterize the behaviour of originating passengers after they have gone through immigration and before going to the gate lounge. It is also used to characterize the behaviour of transfer passengers after they have deplaned from their arrival flight and before going to the gate lounge for their connecting flight.

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			Passenger Type		
			Transfer Passengers	*Originating Passengers with >1 hr to STD*	*Originating Passengers with <1 hr to STD*
Activity Profile	1	The "shopaholic"- Visits the most number of shops, he/she has no preference to type of shops.	-NA-	Visits 4 shops, rest, then 3 shops	-NA-
	2	The DFS shopper- Visits perfumes/ cosmetics, watches, alcohol, fashion, tobacco from DFS.	Visits 6 shops, rest then 2 shop	Visits 2 shops, rest then 1 shop	Visits 2 shops
	3	Typical male- Visits sports shop, electronics, computers, "Sports Arena", books, Singapore Souvenirs.	Visits 6 shops, rest then 2 shop	Visits 3 shops, rest then 1 shop	Visits 3 shops
	4	Typical female- Visits perfumes, cosmetics, chocolates, food, fashion, pharmacy books, Singapore Souvenirs.	Visits 6 shops, rest then 2 shop	Visits 3 shops, rest then 1 shop	Visits 3 shops
	5	Youth- Visits Children's store, gifts & collectibles, chocolates, fashion, internet kiosk, books, Singapore Souvenirs.	-NA-	Visits 3 shops, rest then 1 shop	Visits 3 shops
	6	Business travelers- Visits the CIP lounge.	Go to CIP lounge, then go to gate from CIP lounge.	Go to CIP lounge, then go to gate from CIP lounge.	-NA-

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5.1.3 Simulation Run and Results

Figure 5.1 and Figure 5.2 are screen shots of the simulation result. The average refers to the average of the replication averages. The half width is the half width of the sample mean at 95%. This means that in 95% of repeated trials, the sample mean would be reported as to be within the interval sample mean +/- half width. The minimum and maximum average is the smallest and largest averages across all replications respectively. The maximum value and the minimum value is the largest and smallest value observed across all replications. Table 5.3 summarizes the significant simulation results.

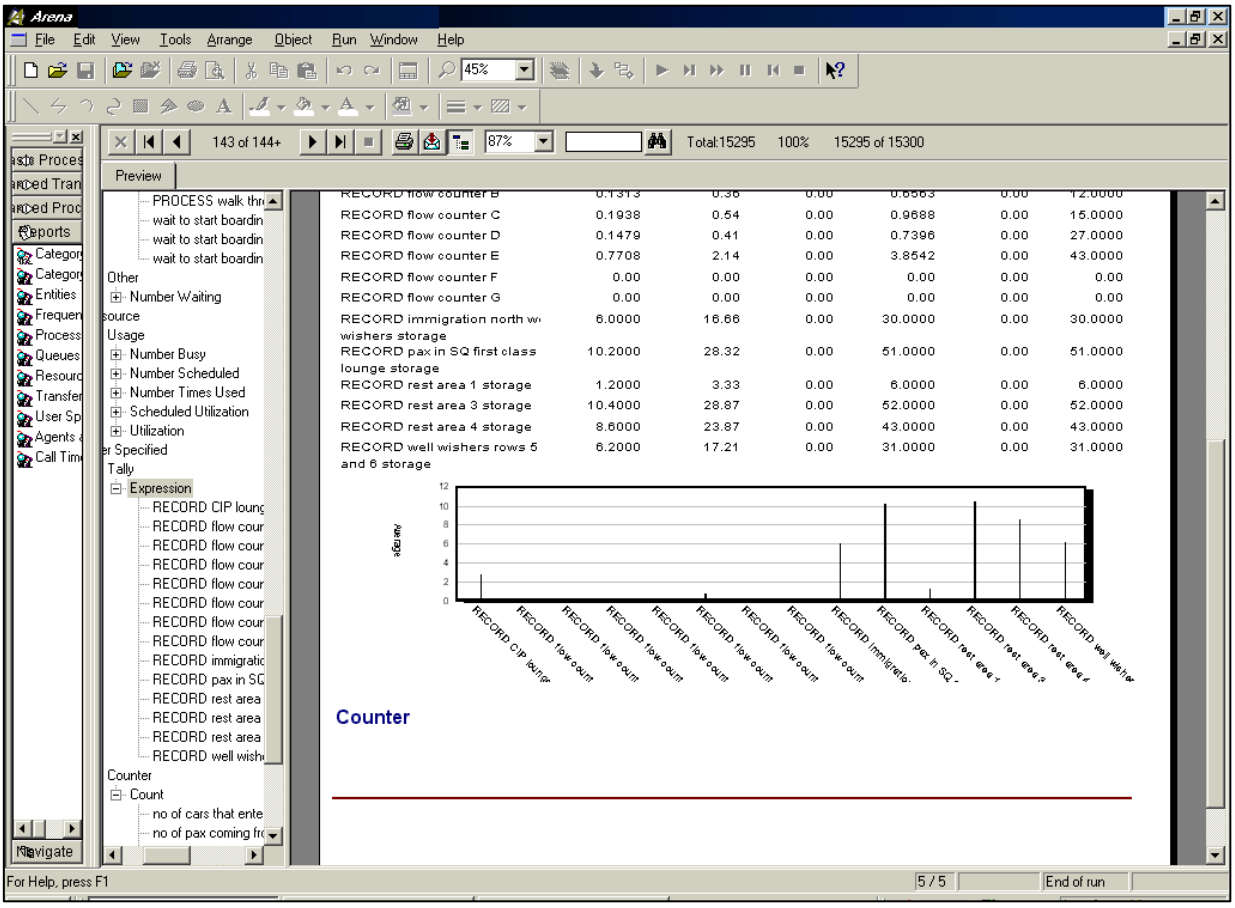

Figure 5.1: ARENA screen shot of simulation results (Counter)

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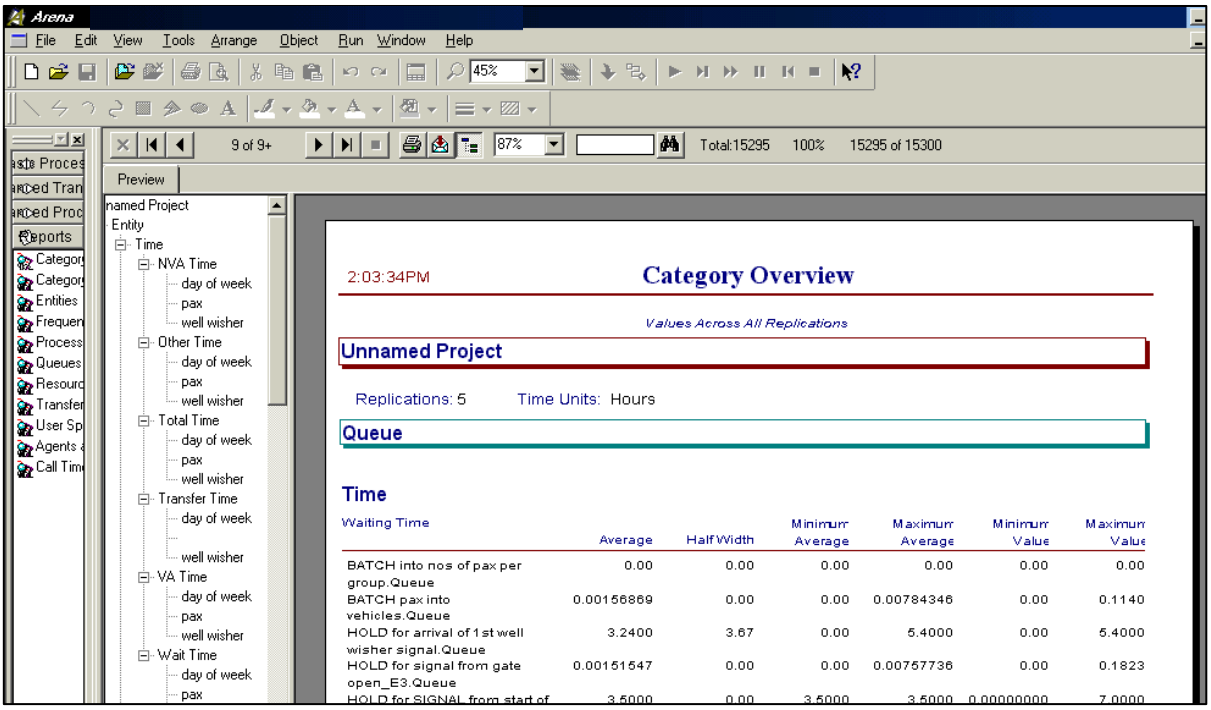

Since performance standards for maximum queue length, waiting time, density and flow rate could not be revealed for comparison with the simulation result due to

Landside Facility	System Performance Indicators	Simulation Results
Check-in	Maximum queue length = Maximum waiting time =	16 32 min
Departure Immigration	Maximum queue length = Maximum waiting time =	8 1 min 37 sec
Gate lounge walk through metal detector	Maximum queue length = Maximum waiting time =	21 5 min
Congestion level of gate lounge	Maximum density=	1.65 m^2/person
Congestion level of flow corridor[1]	Maximum flow rate =	0.43 persons/ min meter

Table 5.3: Summary of simulation results

[1] The congestion level of flow corridor is indicated by the maximum flow rate. Persons per minute is an output of the simulation.

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confidential reasons, the Head of Operations of Terminal 2 from the Civil Aviation Authority of Singapore (CAAS) was asked to give his comments. He commented that the results are acceptable when compared to the performance standards set by CAAS. Since these results are acceptable, it can be concluded that the current number of passengers processing facility is sufficient to meet the peak hour demand.

5.2 Scenario Analysis: Scenario 2- Operation of Airbus A380 on High Density Routes

The simulation model is used to evaluate the impact of airlines operating Airbus A380 aircraft on high density routes. Based on a mixed class seating configuration, the capacity of a Boeing 747-400 aircraft is 416 passengers and that of an Airbus A380 is 555 passengers. The A380 represents a 33% increase in passengers capacity over the Boeing 747-400. In this scenario, airlines planned to operate the A380 on half of the routes that were previously served by the B747-400. Simulation would be carried out to determine the quantity of resources that is required to handle the A380.

5.2.1 Design of Experiment

Similar to the previous section, the demand during the peak hour is of interest in this analysis. Likewise, a warm up period of 6 hours is used to ensure that the simulation model is in steady state and the terminating condition is when the simulation clock is at 0959 hours.

5.2.2 Input Data

The input data used in this scenario is the same as that used in the previous section. The only difference is that half of the flights operated by Boeing 747-400 aircraft is

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replaced by Airbus A380 aircraft. Thus there is a 33% increase in the number of passengers on the affected flights as compared to the previous flight schedule (Figure 5.3).

	Schedule information						Pax information		
S/N	Day	Flight No	Airline code	Aircraft Type	STD		Total No of originating pax	Total No of pax in tour group	Ave No. of pax per group
					hr	min			
6	1	SQ172	1	B772	7	55	76	0	0
7	1	SQ320	1	A380	8	0	354	50	25
9	1	SQ961	1	B744	8	5	145	0	0
10	1	MH602	3	A330	8	15	138	0	0
11	1	MI232	1	A319	8	20	72	0	0
12	1	SQ219	1	A380	8	30	333	60	30
13	1	SQ142	1	B744	8	40	96	0	0

Figure 5.3: Flight schedule operating with Airbus A380 aircraft (Courtesy of CAAS)

Table 5.4 summarizes the results and compares it with the results in Table 5.3. It is observed that operating an A380 aircraft instead of a B747-400 aircraft has the most impact on check-in queue length, check-in waiting time and gate lounge congestion.

The Head of Operations of Terminal 2 from CAAS was again asked to give his comments based on the simulation results (Appendix A). He commented that the maximum waiting time of 1 hour 45 minutes for check-in is unacceptable hence there is a need to increase the number of check-in counters that are manned. There is no need to increase the number of immigration counters because there is only a small increase in maximum waiting time. However, there are insufficient number of security equipment at the gate lounge, resulting in a long queue. Although the maximum waiting time of 12 minutes is just a little over the limit, a queue of 35 passengers will result in massive congestion. The simulation results also showed that the existing gate lounge is too small to accommodate passengers traveling on the A380. The congestion level before the introduction of the A380 was 1.65 m^2/person which corresponds to Level of Service A whereas the congestion level increases to 1.28 m^2/person which

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corresponds to Level of Service B when the A380 is used. The space to be provided for passengers in different functions can be found in Appendix H.

Landside Facility	System Performance Indicators	Scenario 1 Results: (Operating B747)	Scenario 2 Results: (Operating A380)
Check-in	Maximum queue length = Maximum waiting time =	16 32 min	31 1 hour 45 min
Departure Immigration	Maximum queue length = Maximum waiting time =	8 1 min 37 sec	8 1min 39 sec
Gate lounge walk through metal detector	Maximum queue length = Maximum waiting time =	21 5 min	35 12 min
Congestion level of gate lounge	Maximum density=	1.65 m^2/person	1.28 m^2/person
Congestion level of flow corridor [2]	Maximum flow rate =	0.43 persons/ min meter	0.45 persons/min meter

Table 5.4: Comparison of results with operating Airbus A380

Resources that were found to be inadequate were incrementally added and the simulation was re-run. The results were then compared to the base line results where the smaller B747-400 was operated. The above process was repeated until the result showed that the number of passenger processing facility were adequate to maintain the same level of service as when the B747 was operated. A total of 3 simulations were

[2] The congestion level of flow corridor is indicated by the maximum flow rate. Persons per minute is an output of the simulation.

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conducted before this was achieved. Table 5.5 summarizes the results of the performance of the system with different amount of resources.

Landside Facility		Base line Results	Simulation Run 1	Simulation Run 2	Simulation Run 3
Check-in	Amount of resources	7 counters	8 counters	9 counters	10 counters
	Maximum queue length = Maximum waiting time =	31 1 hr 45 min	27 1 hr 30 min	19 50 min	14 32 min
Gate lounge walk through metal detector	Amount of resources	1 set	2 sets	2 sets	2 sets
	Maximum queue length = Maximum waiting time =	35 12 min	28 6 min	28 6 min	28 6 min
Congestion level of gate lounge	Maximum density=	1.28 m^2/person	1.0 m^2/person	1.0 m^2/person	1.0 m^2/person

Table 5.5: Comparison between different amount of resources and system performance

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It was found that 10 counters were needed to achieve the same service standard as when the B747-400 was operated. Two sets of security equipment were also needed at the gate lounge to achieve a service standard that is comparable to before. It was noted that the congestion level in the gate lounge increased from 1.28 m^2/person (Level of Service B) to 1.0 m^2/person (Level of Service C). The reason behind this was that the increase in the number of security equipment at the gate lounge had resulted in a decrease in the waiting time in queue and this means that passengers would go to the next process which is the gate lounge earlier than before. However, the time to board the aircraft remains the same thus there are more passengers in the gate lounge and there is a higher congestion level than before. In order to maintain Level of Service A (1.4 m^2/person), the area of the gate lounge must be expanded by 29%.

5.3 Sensitivity Analysis: Passenger Arrival Profile

Sensitivity analysis can be used to assess the impact of input on simulation results thus identifying what data and variables are important. If an airport planner finds that any input data that has a large impact on the simulation output has been neglected during the initial stage of data collection, he or she can return to collect better quality data before conducting the simulation experiment again. Better quality data can be obtained by collecting more data over a longer period of time to even out any outliers. Another method is to collect data at a higher resolution, for example every 15 minutes instead of every 30 minutes.

In the case of the simulation model for Changi Airport Terminal 2, sensitivity analysis was used to assess the need for collecting data on passenger arrival profile in higher

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resolution. Passenger arrival profile were collected in 5 minutes intervals but were aggregated into 10 minutes and 15 minutes intervals for the purpose of sensitivity analysis (Appendix A). A group of 3 interns spent a total of 5 days collecting these data. The simulation experiment was conducted with these two different sets of passengers arrival profiles and the demand for check-in and immigration resources were compared. Only check-in and immigration resources are of interest because they are solely used by originating passengers thus they are more likely to be affected by different passenger arrival profile.

5.3.1 Design of Experiment

A warm up period of 3 hours is used to ensure that check-in and immigration resources will reach steady state. The terminating condition is when the simulation clock is at 0959 hours.

5.3.2 Input Data

The flight schedule used is the same as that for the scenario analysis conducted in Section 5.1. No arrival flight schedule is necessary since this analysis only concerns demand for resources that serves only originating passengers. The following passengers arrival profile which is in 10 minutes resolution was used:

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X = Current Time – Scheduled Time of Departure		**Probability**	**Cumulative Probability**
X= a	**X= b**	**P(a < X < b)**	**F(*x*) = P(X ≤ x)**
-180	-170	≈ 0	≈ 0
-170	-160	0.01	0.01
-160	-150	0.01	0.02
-150	-140	0.07	0.09
-140	-130	0.08	0.17
-130	-120	0.08	0.25
-120	-110	0.11	0.36
-110	-100	0.13	0.49
-100	-90	0.11	0.60
-90	-80	0.08	0.68
-80	-70	0.12	0.80
-70	-60	0.10	0.90
-60	-50	0.05	0.95
-50	-40	0.03	0.98
-40	-30	0.02	1.00

Table 5.6: Passenger arrival profile in 10 minutes resolution (courtesy of CAAS)

5.3.3 Simulation Run and Results

Table 5.7 compares the result of passenger arrival profile in 10 minutes resolution and 15 minutes resolution. The Head of Operations of Terminal 2 from CAAS was asked to comment on whether the variability in output has any impact on airport operations. With reference to check-in, he commented that a difference of 1 person in the queue

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and a difference of 5 min of check-in maximum waiting time are not significant to airport operations. For the immigration process, he commented that a difference of 1 sec for maximum waiting time is insignificant. As such, it can be concluded that a higher resolution is not necessary and collecting data on passenger arrival at the airport in 15 minutes interval is sufficient.

Landside Facility	System Performance Indicators	Passengers Arrival Profile in 15 mins resolution	Passengers Arrival Profile in 10 mins resolution	% change
Check-in	Maximum queue length = Maximum waiting time =	16 32 min	15 27 min	6.25% 15.6%
Departure Immigration	Maximum queue length = Maximum waiting time =	8 1 min 36 sec	8 1min 37 sec	0 % 1.04%

Table 5.7: Comparison of results with different passenger arrival profile

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CHAPTER 6

CONCLUSION & FUTURE WORK

This chapter concludes the work completed and suggests possible future work.

6.1 Conclusion

The trend towards private sector participation in airports, airline industry deregulation, formation of airline alliance, unstable geo-political situation and prevalence of Information and Communication Technology has resulted in a number of challenges for airport planners. Airport planners are faced with managing volatility in passenger traffic, meeting the needs of different airlines and security requirements and at the same time driving the bottom line. These trends and challenges have made airport landside capacity planning a complex task. Many methods have been proposed for airport landside capacity planning. These methods include using rule-of-thumbs, queuing theory, mathematical programming, data envelopment analysis (DEA), simulation modeling, and the use of a Decision Support System (DSS).

This study developed a framework for simulation based decision support system for airport landside capacity planning. It consist of the components that made up a DSS for airport landside capacity planning and steps for the development of a DSS for airport landside capacity planning. A DSS consist of the database management sub-system, model management sub-system and user interface sub-system. The steps for the development of a DSS are to understand the operations of the airport understudy, set the objective of the airport in terms of performance indicators and design capacity, preliminaries to the DSS development process, system analysis, system design, implementation of the DSS, operation and modification of the DSS. The system design

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implementation step forms a loop and this iterative process will eventually lead to a complete DSS.

This study also developed the simulation model for the DSS's model management sub-system. Simulation modeling of Changi Airport Terminal 2 was carried out using a commercial-of-the-shelf (COTS) simulation software, ARENA. Two scenario analysis were carried out. The first scenario analyse the queue length, waiting time and congestion level during the peak hour. The second scenario analyse the impact on queue length, waiting time and congestion level should airlines replace the Boeing 747 aircraft with the bigger Airbus A380 aircraft on high density route. A sensitivity analysis was also carried out to assess the impact of passenger arrival profile at the airport.

6.2 Future Work

This study developed a simulation model for the model management sub-system. However, the database management sub-system and user interface sub-system were only presented on a conceptual level. Future work could be done by following the steps in section 3.4 (Steps for Developing a DSS for Airport Landside Capacity Planning) to develop these two sub-systems and integrate them to the model management sub-system to form a complete DSS.

Future work could also develop an Artificial Intelligence (AI) machine learning programme which aims to correct inaccuracy in simulation modeling. This machine learning programme shall be given actual survey data of queue length and waiting time for a particular time on a particular day. It then compares it with the simulation results when the simulation is carried out for the same period. With continuous examples of

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input and output, the AI module will discover a function that when combine with input parameters is able to generate more accurate simulation output. In essence, this set up has created a feedback loop for the simulation model and enable it to produce more accurate simulation results. Figure 6.1 illustrates this concept.

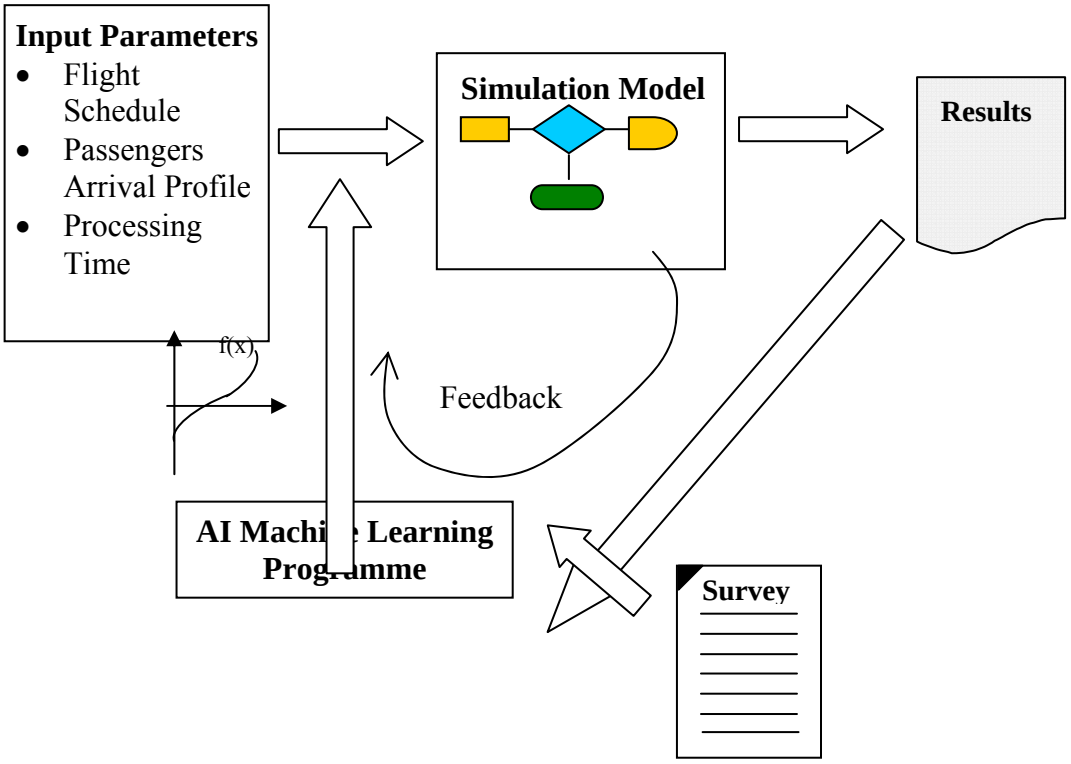

Figure 6.1: Using an Artificial Intelligence Learning programme with a Simulation Model

In addition, future work could also develop an optimization algorithm whereby airport planners could input into the DSS performance standards and the DSS shall use the simulation model to determine the number of passengers processing facility that are required to meet the performance standard set. This would save time for airport planner because it does away with the need to repeatedly add resources for passenger processing and re-run the simulation to compare the results until the service standard is achieved.

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Interview Structure & Notes Appendix A

This appendix contains interview notes with the people who were interviewed as part of this study. The table below summarizes the people who are interviewed and the information that they have given.

Name	**Designation & Organization**	**Information given**
Desmond Chong	Head of Operations, Terminal 2. Civil Aviation Authority of Singapore	• Passenger Handling Process • Simulation model validation • Comments on simulation results
Zhuang Hanqi	Engineer, Airport Planning. Civil Aviation Authority of Singapore	• Airport design capacity • Passenger processing time • Load factor • Ground access split • Passenger arrival profile • Percentage of passengers for secondary security screening
Tua Phuat Siong	Senior Manager, Changi Airport International	• Experience of working with overseas airport operators.
Chua P.H	Commercial Manager, DFS Galleria	• Passengers shopping profile.

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1st Interview with Mr Desmond Chong, Head of Operations Terminal 2, Civil Aviation Authority of Singapore.

Introduction 1. Objective of the interview as part of my studies 2. Building simulation model 3. The need for me to understand passenger processes	
Questions	Response
1. Describe the following areas:	
a. Curb - no. of entrances - operations at the curb	- 4 entrances. - Singapore Airlines first class passengers will go to entrance 1. - Tour bus will stop at entrance 4. - A car normally takes 3 passengers.
b. Check-in hall - check-in hall set up - queue discipline - check-in row assignment	-12 check-in rows form 6 islands. 1 row has 12 check-in counters. - All counters in each row shares 1 queue. -Universal check-in allowed[1]. Row 1: Air France Row 2: Silk Air Row 3: Lufthansa, Air New Zealand Row 4: Star Alliance Priority Passengers Row 5: Crew & Internet bag drop Row 6 & 7: Singapore Airlines common check-in Row 8: Not used

[1] Universal check-in, also known as common check-in allows the flexibility for any counter to accept bags for any flight.

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	Row 9: Royal Brunei, Philippines Row 10: Group check-in Row 11: Malaysia Airlines Row 12: Kuala Lumpur shuttle flights
c. Immigration hall - immigration counter set up - queue discipline	- 8 counters in the north side of the terminal - 8 counters in the south side of the terminal. - Each counter has one queue in front of it. No counter for priority passengers.
d. Departure/ Transit hall	- Passengers rest, shop and eat. - Passengers will stay in the departure/ transit hall until one hour before flight departure.
e. Gate lounge	- Gate lounge will open 1 hour before ETD[2]. - Pre-board screening is carried out at the gate lounge. Pre-board screening consists of a walk through metal detector and x-ray of cabin bags. - Secondary screenings are hand search of cabin bags and HHMD[3]. - All gates have one set of security equipment. Gates E7, E8 and E12 are common gate lounge shared by 3 aircraft contact stands. - 3 sets of security equipment for common gate lounge.
2. Describe the processes these passengers go through	
a. Originating passengers - arrival profile	- Originating passengers arrive between 2.5 hours to 40 minutes before STD[4].

[2] Estimated Time of Departure. ETD reflects the departure time on the actual day of the flight. It will deviate from the Scheduled Time of Departure (STD) due to reasons such as late arrival of incoming aircraft.

[3] Hand Held Metal Detector.

[4] Scheduled Time of Departure. STD is frequently known as the flight schedule and passengers base on this to book their flights.

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- any special group?	- Tour group normally arrives early, about 2 hours 20 minutes and would have all arrived by 2 hours before STD. - Airport Planning section shall provide arrival profile. - Originating passengers go through the process of check-in, immigration, spend time in the departure/transit hall and then proceed to the gate lounge for boarding one hour before STD. - Gate editing is done right after pre-board screening. - Priority is given to special needs passengers, first class, then business class.
b. Transfer passengers - Need for re-check in? - transfer passengers dwell time	- Nearly all transfer passengers are through checked[5]. - Passengers will deplane, spend time in the departure/transit hall and then proceed to the gate lounge for boarding one hour before STD. - Airport Planning section shall provide transfer dwell time.
c. Terminating passengers	- Terminating passengers are not separated from transfer passengers and originating passengers in the departure/transit hall. - They will deplane, move through the departure/transit hall and go down one level to the arrival hall.
d. Well-wishers	- Well-wishers will accompany originating passengers in the check-in hall until they enter the

[5] Through check passengers are transfer passengers who are checked in and have collected their boarding pass for their connecting flight.

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	police check point before immigration. - Average of 1 passenger to 1.5 well-wisher. - For Haj[6] flights the ratio is 1 passengers to 15 well-wishers.
Request Data	
1. Flight schedule 2. Gate allocation 3. Load factor[7] 4. Ground access split[8] 5. Process time at curb 6. Passenger arrival profile 7. Check in process time 8. Immigration process time 9. Number of cabin bags 10. Cabin bags x-ray process time/ throughput 11. % secondary screening- walk through & cabin bags x-ray 12. HHMD process time 13. Hand search process time 14. Performance indicators 15. How are performance measured?	1. Provided. 2. Provided. 3. Airport Planning section shall provide this. 4. Airport Planning section shall provide this. 5. Airport Planning section shall provide this. 6. Airport Planning section shall provide this. 7. Airport Planning section shall provide this. 8. Airport Planning section shall provide this. 9. Airport Planning section shall provide this. 10. Airport Planning section shall provide this. 11. Airport Planning section shall provide this. 12. Airport Planning section shall provide this. 13. Airport Planning section shall provide this. 14. Confidential. 15. CAAS engage survey companies to do survey on queue length and waiting time.
Interview close 1. Thank you 2. Since performance indicators are confidential, I will ask you to	

[6] Charter flights for religious groups
[7] Percentage of the aircraft seats that are filled
[8] Percentage of passengers and public who arrives via bus, train and cars

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comment on simulation results after the simulation is ready.	

2nd Interview with Mr Desmond Chong, Head of Operations Terminal 2, Civil Aviation Authority of Singapore.

Introduction 1. Objective of this interview - validation - comment on results of scenario analysis - sensitivity analysis 2. Explain what is validation & sensitivity analysis	
Questions	Response
Validation 1. Does the animation represent what you observe on the ground?	Yes.
Scenario Analysis 1. Scenario 1: Peak hour analysis. a. Explain this scenario and look at result b. Ask to comment on results - check-in - immigration - gate lounge walk through metal detector - congestion of gate lounge	 -ok -ok -ok -ok

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- congestion of flow corridor	-ok
2. Scenario 2: A380 a. Explain this scenario and look at the result b. Ask to comment on results - check-in - immigration - gate lounge walk through metal detector - congestion of gate lounge - congestion of flow corridor	 - unacceptable - ok - Although waiting time is only a little over the limits, but there is massive congestion. - Drop in Level of service. Changi service is higher than Level of Service B. - ok
<u>Sensitivity Analysis</u> 1. Explain what input parameter is analysed 2. Ask to comment on results - check-in - immigration	 - A difference of 1 person in the queue and a difference of 5 min for check-in maximum waiting time have minimum impact on airport operations. - A difference of 1 sec for maximum waiting time is insignificant.

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Interview with Ms Zhuang Hanqi, Engineer, Airport Planning, Civil Aviation Authority of Singapore.

Introduction 1. Objective of my study 2. Building simulation model 3. The need for the following data.	
Questions	Response
1. T2 design capacity 2. Definition of design peak hour & peak hour capacity	- 23 million passengers per annum - use 40th peak for design. Peak hour capacity is 4,900 passengers.
Request Data	
1. Load factor[9] 2. Ground access split[10] 3. Process time at curb 4. Passenger arrival profile 5. Check in process time 6. Immigration process time 7. Number of cabin bags 8. Cabin bags x-ray process time/ throughput 9. % secondary screening- walk through & cabin bags x-ray 10. HHMD process time 11. Hand search process time 12. Transfer dwell time	1. Provided. 2. Provided. 3. Provided. 4. Provided. 5. Provided. 6. Provided. 7. Provided. 8. Provided. 9. Provided. 10. Provided. 11. Provided. 12. Provided.
Interview close	

[9] Percentage of the aircraft seats that are filled
[10] Percentage of passengers and public who arrives via bus, train and cars

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1. Thank you. 2. Will contact you if there are further data that is needed.	

Telephone Interview with Mr Tua Phuat Siong, Senior Manager, Changi Airport International.

Introduction 1. Objective of my study 2. Building simulation model 3. Examples of input data that is needed for simulation model	
Questions	Response
1. Does overseas airport operators keep detailed records of data?	- No. Most are only able to provide very recent data. - Sample size is not large enough.
2. Can you start collecting more data once you realize that they cannot provide you with the amount of data you need?	- Yes, can start collecting data. - But there is not enough time. Deadline to propose a recommendation is tight.
3. So what can you do about it?	- Try the best to make do with what is given.
Interview close 1. Thank you 2. Will contact you if there are further questions	

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Interview with Ms Chua P.H, Commercial Manager, DFS Galleria.

Introduction 1. Objective of the interview as part of my studies 2. Building simulation model 3. The need for me to understand passenger activity profile in the departure/transit hall	
Question	Response
1. The simulation model is built to allow for 6 different activity profiles. Can you classify the activity of passengers in the departure/transit hall into 6 profiles?	The profiles are: - "Shopaholic" or "window shopper". They have no preference of shops and will visit all shops - Shoppers who visit shops selling duty free goods and luxury fashion products - Male vacation shopper who visits electronics shops, sports shops, book shop and souvenir shops. - Female shopper who visits perfume & cosmetic shops, chocolates, fashion and souvenir shops. - Family with young children who visits toy stores, chocolates, book shop and souvenir shops. - Business travelers may visit one or two souvenir shops if it is on the way to their lounge. Frequent travelers will normally not visit any shops.
2. Other than shopping, what else do passengers like to do in the departure/transit hall.	- Use the internet kiosk, rest at the snooze area, use the free leg massage machine. - Man likes to watch the sports channel.
3. How many shops does a passenger normally visits?	- Depends on how much time they have. - Most will visit a maximum of 3 shops if they have

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	only one hour left. - Transfer passengers have a longer dwell time. So they visit about 6 to 8 shops and rest.
<u>Interview close</u> 1. Thank you 2. Will contact you if there are further questions	

Data Stored in the Database Management Sub-System Appendix B

Function	Database Fields	Data	Derivation of Data for ARENA	Usage in ARENA
Originating Passengers				
Importing departure flight schedule & generation of originating passengers	Schedule time of departure	Flight number, Schedule Time of Departure	Convert hours and minutes into hours	READ next departure time; flight schedule.txt
	Airline type	Singapore Airlines; Star Alliance; Others	No derivation needed	READ airline; airline.txt
	Number of passenger (not in tour group)	Number of passengers	No derivation needed	READ no of passengers; org passengers.txt
	Number of passenger (in tour group)	Number of passengers	No derivation needed	READ group check in passengers.txt; passengers per group.txt
Modeling ground access mode	Number of passengers using bus, train and car to reach the airport	bus, train, car	Calculate percentage	DECIDE on mode of transport
Curb process	Percentage of vehicles stopping at various	Entrance 1, Entrance 2, Entrance 3, Entrance 4	Calculate percentage	DECIDE which curb entrance to stop at

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Function	Database Fields	Data	Derivation of Data for ARENA	Usage in ARENA
	entrances			
	Process time for unloading bags from vehicle	Time	Estimate probability distribution function	PROCESS unload bags
	Passengers to vehicles ratio	Number of passengers per car	Calculate average	BATCH passengers into vehicles
Check-in	Passenger arrival profile	Current time – Scheduled time of departure	Estimate probability distribution function	DELAY module; EXPRESSION delay time
	Check-in row assignment	Row 1,2,3… N	No derivation needed	READ check in row.txt
	Percentage of priority check-in passengers	Number of passengers	Calculate percentage	DECIDE priority and other check in
	Process time for check in	Time	Estimate probability distribution function	PROCESS row x counter x; EXPRESSION check in process time
	Gate assignment	Gate 1,2,3…. N	No derivation needed	READ gate; gate assignment.txt
Immigration	Process time for immigration	Time	Estimate probability distribution function	(PROCESS) iNC x
Gate Lounge	Percentage of passengers	Number of passengers	Calculate percentage	DECIDE pass walk through

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Function	Database Fields	Data	Derivation of Data for ARENA	Usage in ARENA
	that pass the security screening (walk through detector)			metal detector
	Process time for secondary screening using hand held metal detector	Time	Estimate probability distribution function	PROCESS hand held metal detector
	Percentage of cabin bags that fails x-ray	Number of bags that fails x-ray	Calculate percentage	DECIDE hand search cabin bags
	Process time for hand search	Time	Estimate probability distribution function	PROCESS hand search cabin bags
	Process time at gate editing counter	Time	Estimate probability distribution function	PROCESS gate editing counter
Transfer Passengers				
Importing arrival flight schedule & generation of transfer passengers	Schedule time of arrival	Flight number, Schedule Time of Arrival	Convert hours and minutes into hours	READ next arrival time; arrival flight schedule.txt
	Arrival gate	Gate 1,2,3…. N	No derivation needed	READ arrival gate; arrival gate.txt

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Function	Database Fields	Data	Derivation of Data for ARENA	Usage in ARENA
	Number of passengers from one arrival flight connecting to the 3 departing flights	Flight number 1, number of passengers, Flight number 2, number of passengers, Flight number 3, number of passengers,	No derivation needed	READ no of transfer passengers_1; no of transfer passengers_1.txt; READ no of transfer passengers_2; no of transfer passengers_2.txt; READ no of transfer passengers_3; no of transfer passengers_3.txt
	Departure time for the 3 connecting flights	Flight number 1, STD, Flight number 2, STD, Flight number 3, STD	Convert hours and minutes into hours	READ connecting flight schedule_1; connect flt sch_1.txt; READ connecting flight schedule_2; connect flt sch_2.txt; READ connecting flight schedule_3; connect flt sch_3.txt;
	Gates assignment for the connecting flights 1,2,3	Gate 1,2,3…. N	No derivation needed	READ connecting gate_1; connecting gate_1.txt; READ connecting gate_2; connecting gate_2.txt; READ connecting gate_2; connecting gate_2.txt;

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Function	Database Fields	Data	Derivation of Data for ARENA	Usage in ARENA
Terminating Passengers				
Departure/Transit Hall	Number of terminating passengers	Number of passengers	No derivation needed	READ no. of terminating passengers; no of terminating passengers.txt
	Claim carousel assignment	Belt 1,2,3… N	No derivation needed	READ belt; belt assignment.txt
Well Wishers				
Check-in Hall	Number of well-wishers	Flight number, number of well-wishers	No derivation needed	READ no. of well-wishers; well wishers.txt
	Check-in row assignment of accompanied passengers	Check in row	No derivation needed	READ check in row_well wishers; check in row_well wishers.txt

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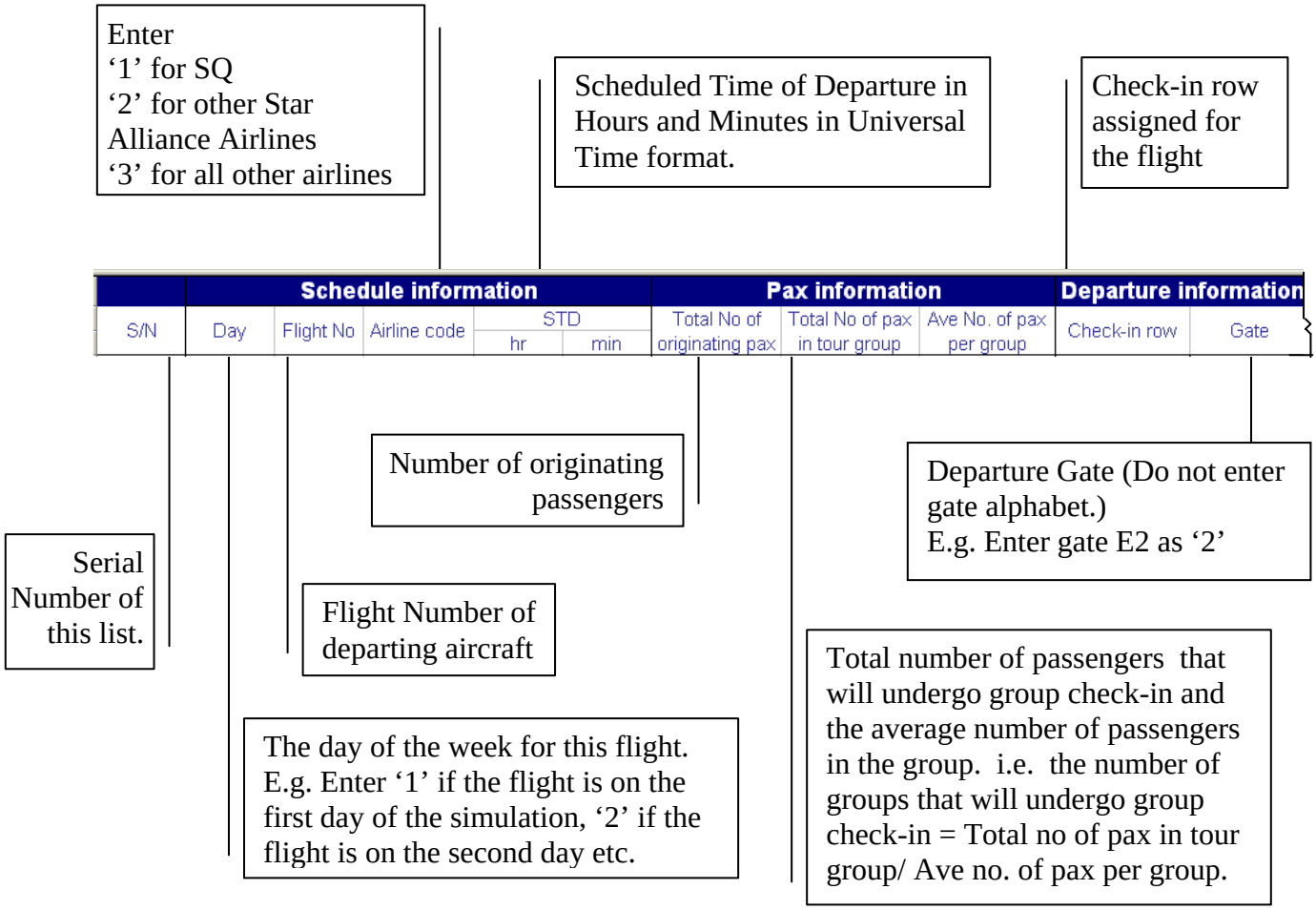
This appendix provide a guide to input simulation data into ARENA and how to setup ARENA to run the simulation. A Microsoft Excel® spreadsheet for departure flights and arrival flights has been designed to aid this process.

Enter Departure Flight Information

Step 1: Enter data concerning departure flights in the "user input" tab:



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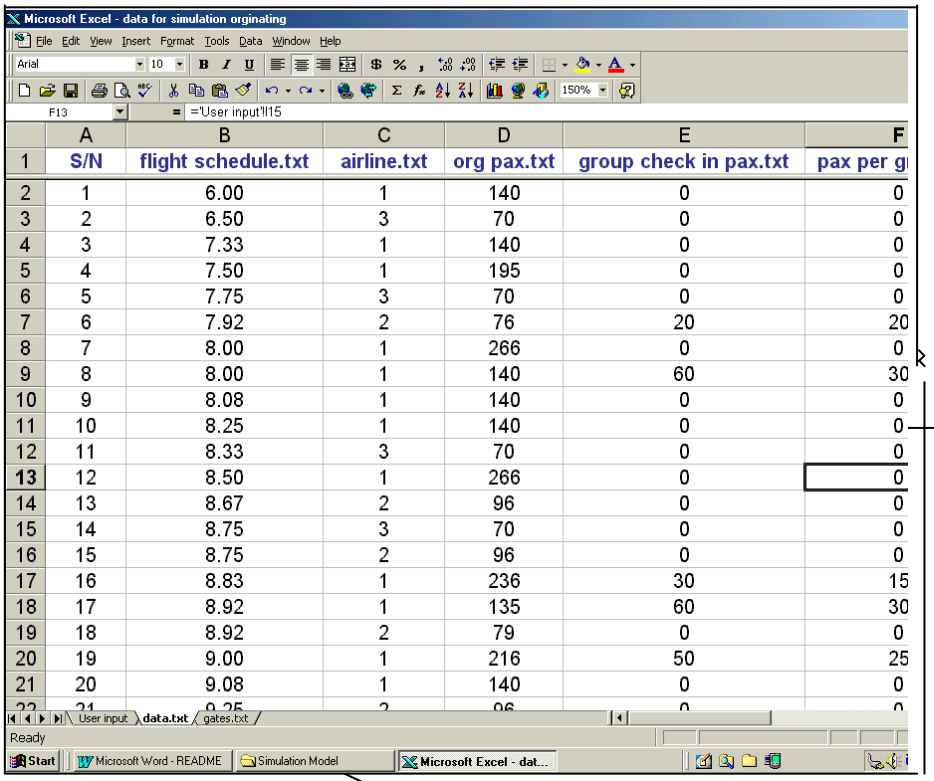
Step 2: Click on the tab "data.txt" and copy the data from columns B to J and save them into their respective text files. ARENA will read from these text files when the simulation is run.



	A	B	C	D	E	F
1	S/N	flight schedule.txt	airline.txt	org pax.txt	group check in pax.txt	pax per g
2	1	6.00	1	140	0	0
3	2	6.50	3	70	0	0
4	3	7.33	1	140	0	0
5	4	7.50	1	195	0	0
6	5	7.75	3	70	0	0
7	6	7.92	2	76	20	20
8	7	8.00	1	266	0	0
9	8	8.00	1	140	60	30
10	9	8.08	1	140	0	0
11	10	8.25	1	140	0	0
12	11	8.33	3	70	0	0
13	12	8.50	1	266	0	0
14	13	8.67	2	96	0	0
15	14	8.75	3	70	0	0
16	15	8.75	2	96	0	0
17	16	8.83	1	236	30	15
18	17	8.92	1	135	60	30
19	18	8.92	2	79	0	0
20	19	9.00	1	216	50	25
21	20	9.08	1	140	0	0

Step 3: Click on the tab "gates.txt" and delete all the '0' from the cells in the spreadsheet. Copy the remaining data and paste it in their respective file names (e.g. save the data in column B as "E1 next departure time.txt").

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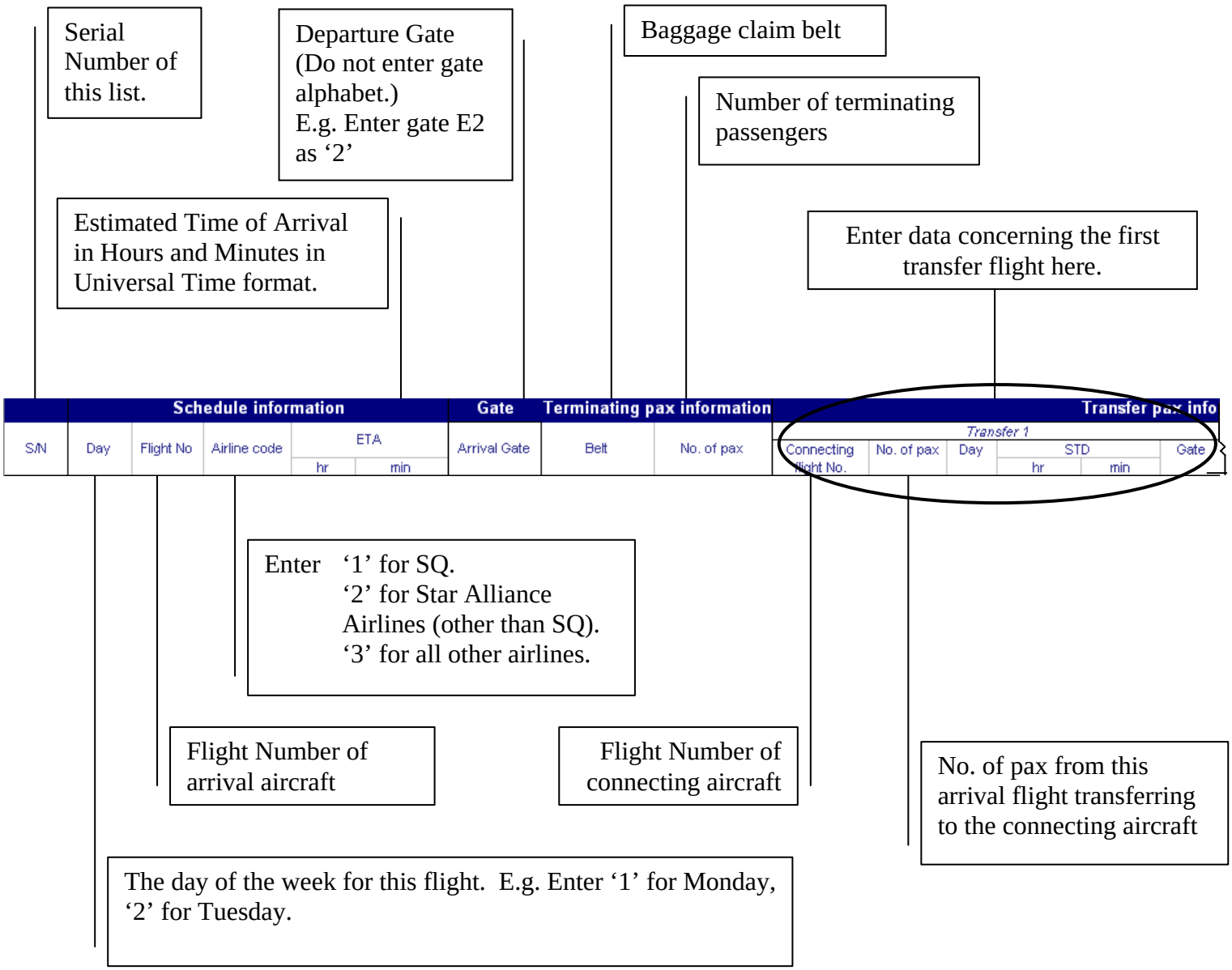
Enter Arrival Flight Information

Step 1: Enter data concerning arrival flights in the "user input" tab:



Step 2: Click on the tab "data.txt" and copy the data from columns B to J and save them into their respective text files. ARENA will read from these text files when the simulation is run.

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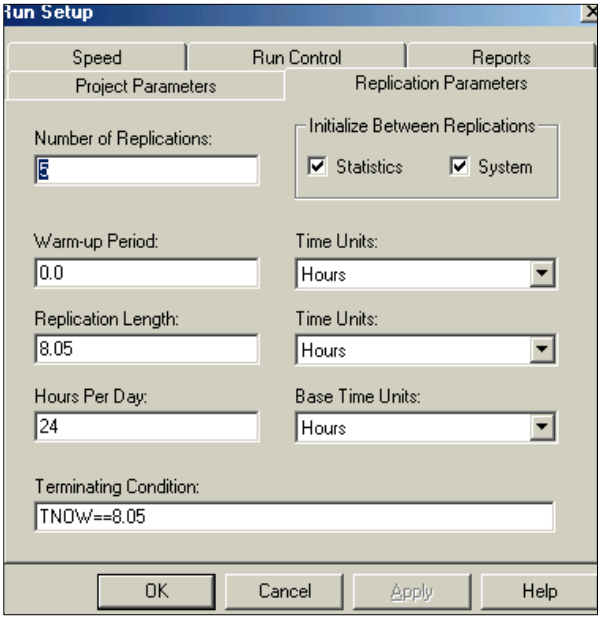
Run Simulation

Step 1: Click on Run on the main menu and choose Setup. The Run Setup dialogue box will appear on the screen.

Step 2: Choose the tab folder "Replication Parameters". This is where parameters for the design of experiment is entered.



Special attention is to be paid to the parameters "Replication Length" and "Terminating Condition". These two parameters are the total number of hours the simulation is run. For example, if the simulation is run for 2 days and 10 hours (including warm-up period) then

Replication Length = 2*24 + 12 (hrs)

Leaving the replication length or the terminating condition blank will result in an infinite loop.

Step 3: Click the "Reports" tab folder and choose "Category Overview" from the "Default Report" drop-down list box. Most of the parameter names in this model are very long and choosing other forms of reports will result in the truncation of the name of the parameter thus making the simulation result impossible to be understood.

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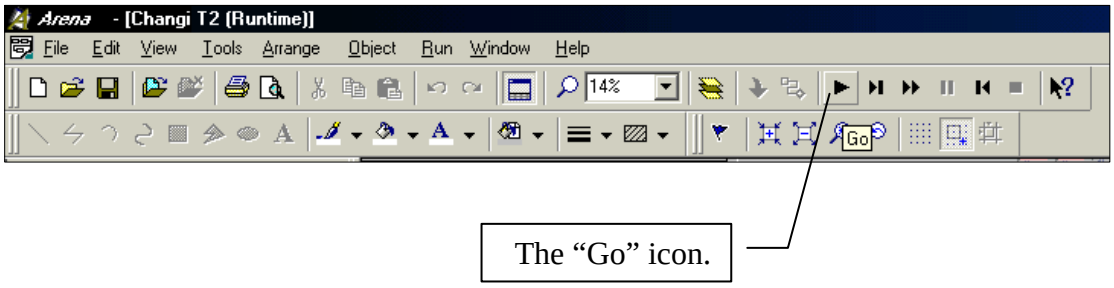
Step 4: Click on the "Speed" tab folder and set the "Animation Speed Factor" to 0.06. This is the recommended speed for this model so that the animation could be clearly seen. The animation speed can still be increased or decreased during the simulation by pressing the ">" or "<" key on the keyboard.

Step 5: Click on the buttons "Apply" and "OK" to accept the changes and exit this dialogue box.

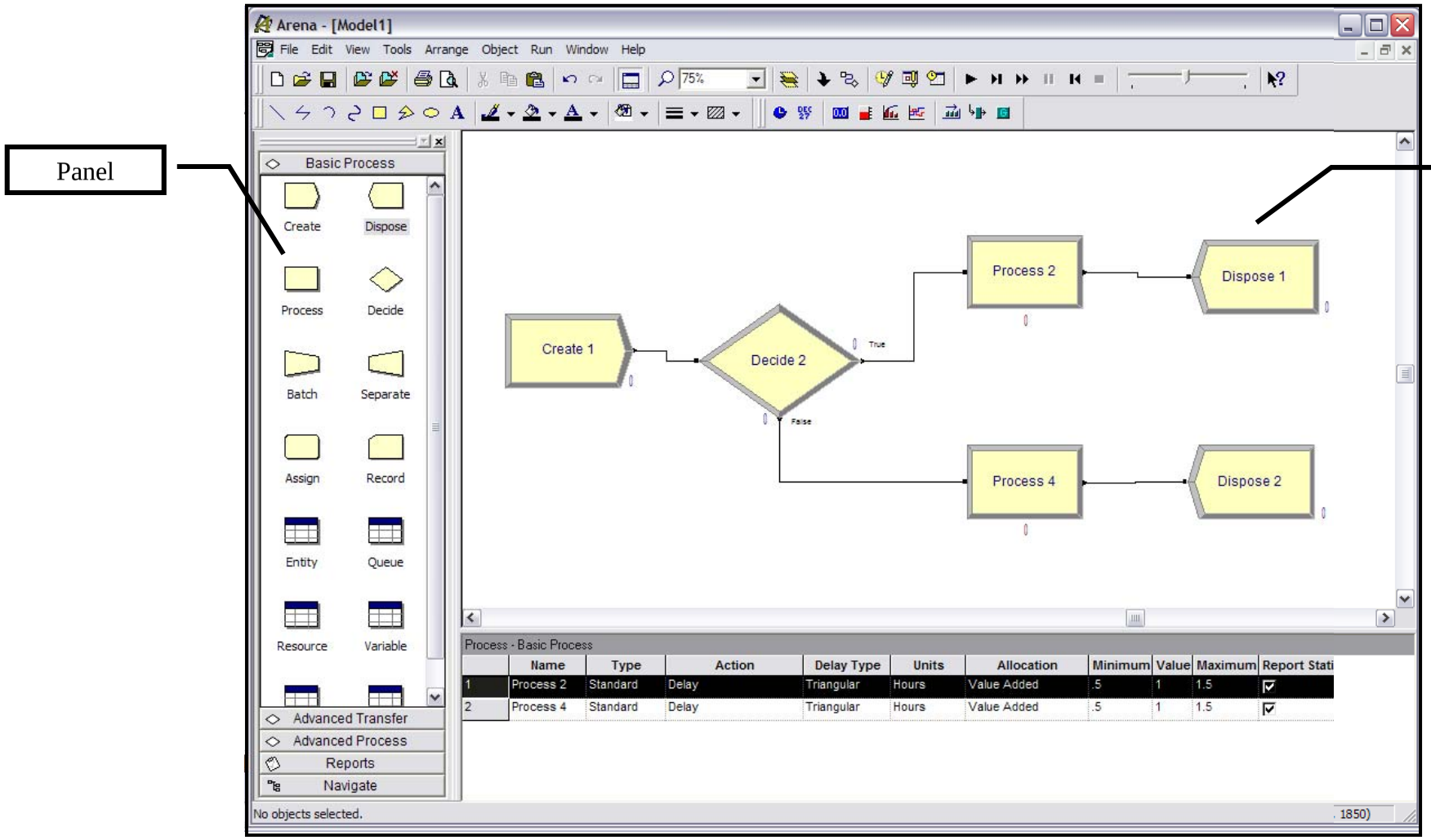
Step 6: Click on the "Go" icon on the menu bar to run the simulation. User can navigate through the model from the "Navigate" panel on the left hand side of the screen



Step 7: At the end of the simulation, the results will be displayed on the screen.

ARENA's User Interface

Appendix D



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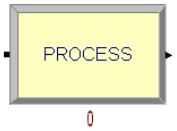
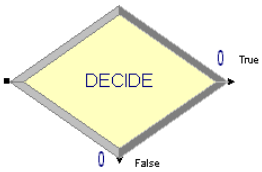
Commonly Used ARENA Modules Appendix E

This appendix summaries some of the ARENA modules used to simulate passengers handling processes at an airport. ARENA uses standard industrial engineering symbols to construct a flow chart that depict the processes passengers have to undergo.

Modules	Description
	This module is the starting point for entities in a simulation model. Entities are created by this module before it begin processing through the system.
	This module is used to model the processing of an entity. Resources to be seized are also specified. The process time is allocated to the entity and may be considered to be non-value added, or value added, in which case it will be computed as a component of the cycle time.
	This module allows for decision-making processes in the system. It includes options to make decisions based on one or more conditions (e.g. entity type) or based on one or more probabilities (e.g. 75% true; 25% false). Conditions can be based on attribute values, variable values, the entity type, or an expression. This module can also be used to compare the equality of two expressions.

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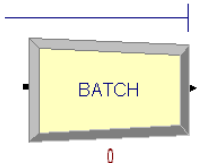
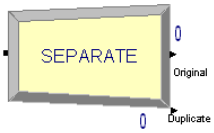
Modules	Description
	This module is used to assign new values to variables, entity attributes, entity types, entity pictures, or other system variables. Multiple assignments can be made with a single ASSIGN module.
	This module is used as a grouping mechanism. Batches may be made with any specified number of entering entities or may be matched together based on an attribute. Entities arriving at the BATCH module are placed in a queue until the required number of entities has accumulated. Once accumulated, these entities will be batched as a new representative entity.
	This module can be used to either copy an incoming entity into multiple entities or to split a previously batched entity. When splitting existing batches, the temporary representative entity that was formed is disposed and the original entities that formed the group are recovered. When duplicating entities, the specified number of copies is made and sent from the module. The original incoming entity also leaves the module.
	This module is used to collect statistics in the simulation model. Various types of observational statistics are available, including time between exits through the module and interval statistics (from some time stamp to the current simulation time). A count statistic is available and it will count the number of entity going through this module.

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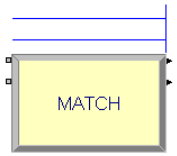
Modules	Description
	This module is the ending point for entities in a simulation model.
	The DELAY module delays an entity by a specified amount of time. When an entity arrives at a DELAY module, the entity remains in the module for the specified time period. The time is then allocated to the entity's value added or non-value added time.
	This module is used to read data from an external file and assign the data values to a list of variables or attributes. When an entity arrives at this module, the values of the attributes, variables, or expressions listed in the specified file are read and assigned as a variable or an attribute.
	The MATCH module brings together entities waiting in different queues. The match may be accomplished when there is at least one entity in each of the desired queues. Additionally, an attribute may be specified such that the entities waiting in the queues must have the same attribute values before the match is initiated. When an entity arrives at the MATCH module, it is placed in one of the associated queues, based on the entry point to which it is connected. Entities will remain in their respective queues until a match exists. Once a match exists, the two entities are then synchronized to depart from the module from its respective exit point.

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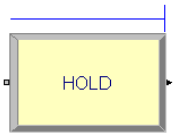
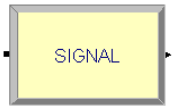
Modules	Description
	This module will hold an entity in a queue to either wait for a signal or wait for a specified condition to become true. If the entity is holding for a signal, the SIGNAL module is used to allow the entity to move on to the next module. If the entity is holding for a given condition to be true, the entity will remain at the module until the condition(s) becomes true.
	The SIGNAL module sends a signal value to each HOLD module in the model which in turn releases the entities it held. When an entity arrives at a SIGNAL module, the signal code is sent. At this time, entities at the HOLD modules that are waiting for the same signal are removed from their queues. The entity sending the signal then continues processing until it is disposed.
	This module adds an entity to storage. The UNSTORE module may then be used to remove the entity from the storage. When an entity arrives at the STORE module, the storage counter is incremented, and the entity immediately moves to the next module. Storages are useful for displaying entity animation while an entity undergoes processing or delay in other modules. Additionally, statistics may be kept on the number of entities in storage.
	The UNSTORE module removes an entity from storage. When an entity arrives at the UNSTORE module, the storage counter is decreased and the entity immediately moves to the next module.

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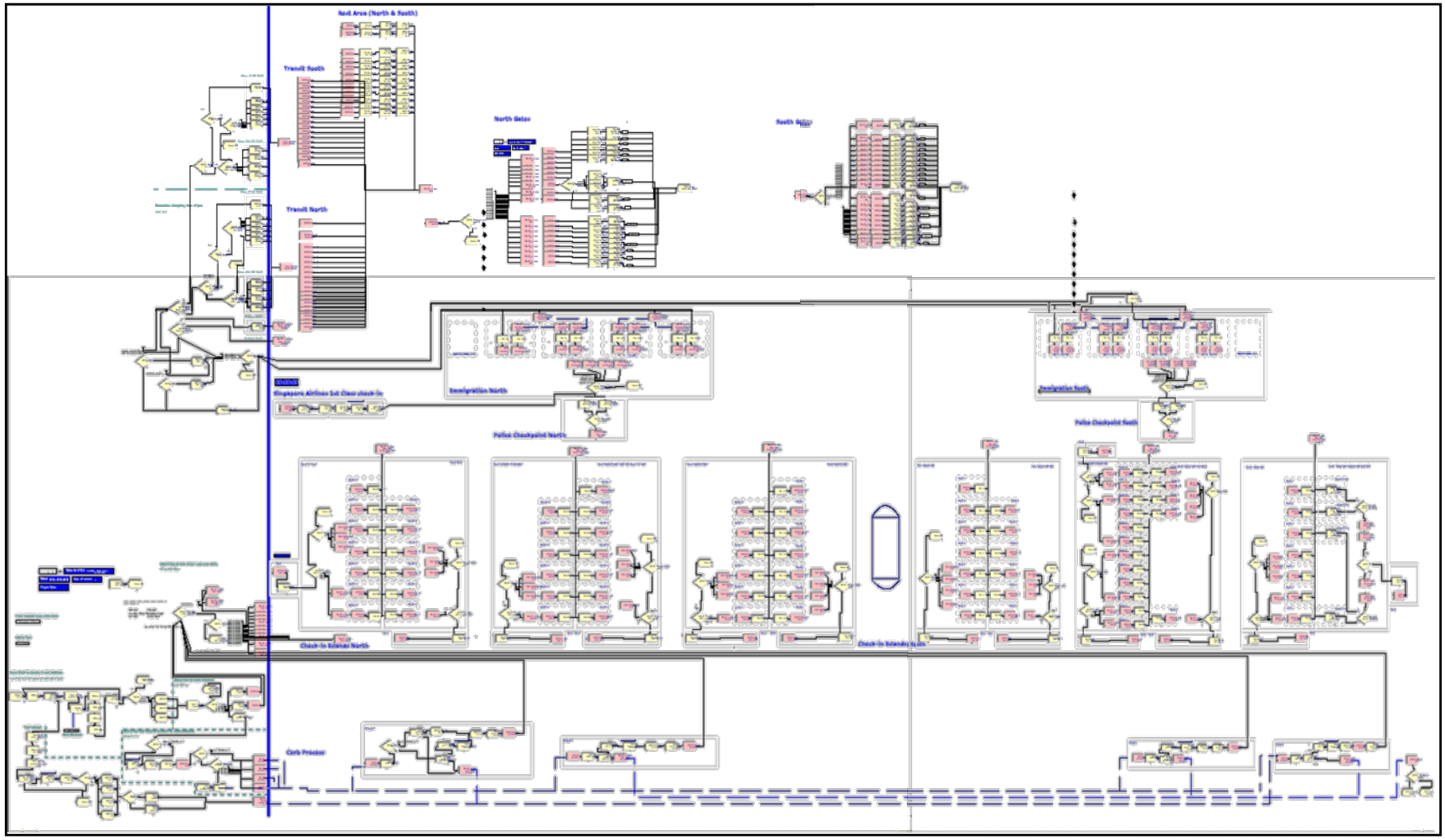
Modules	Description
	The STATION module defines a station (or a set of stations) corresponding to a physical or logical location where processing occurs.
	The ROUTE module transfers an entity to a specified station, or the next station in the station visitation sequence. A delay time to transfer to the next station may be defined. If the station destination is entered as Sequential, the next station is determined by the entity's sequence which is defined in the SEQUENCE data module.
	The PICKSTATION module allows an entity to select a particular station from the multiple stations specified. This module picks among the group of stations based on the selection logic defined in the module. The entity will be routed to the station specified. The station selection process is based on the minimum or maximum value of a variety of system variables and expressions, for example queue length.



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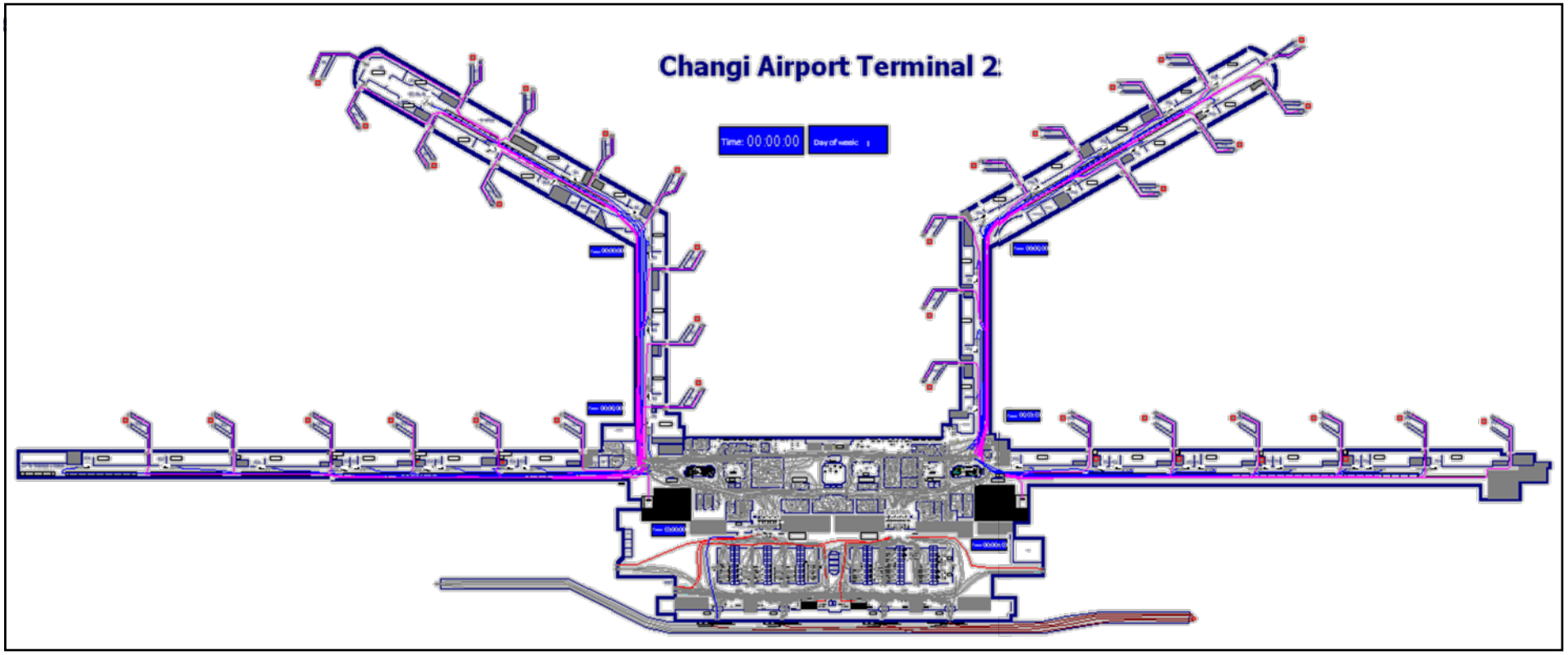
Animation of Simulation Model

Appendix G



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Appendix H

SPACE TO BE PROVIDED FOR PASSENGERS IN DIFFERENT FUNCTIONS

ACTIVITY	SITUATION	LEVEL OF SERVICE STANDARD					
		A	B	C	D	E	F
Waiting and circulating	Moving about freely	2.7	2.3	1.9	1.5	1.0	Less
Bag claim area (outside claim devices)	Moving, with bags	2.0	1.8	1.6	1.4	1.2	Less
Check-in queues	Queued, with bags	1.8	1.6	1.4	1.2	1.0	Less
Hold room; government inspection area	Queued, with bags	1.4	1.2	1.0	0.8	0.6	Less

Source: International Air Transport Association. 2004. Airport Development Reference Manual. 9th ed. Montreal, Quebec, Canada.

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