Brunel University
College of Engineering, Design and Physical Sciences
Electronic and Computer Engineering

Intelligent Optimisation System for Airport Operation: Hajj Terminal in Saudi Arabia

Mohammed Ghazi Gronfula

A thesis submitted for the degree of Doctor of Philosophy

August 2014

Abstract

Airport operation level of service (LOS) and performance management are among the major concerns by any airport authority. Two aspects considered in that kind of measurement: passengers prospective and operators prospective. This thesis tries to combine both in its produced optimisation system. This study was carried out in the Hajj terminal of the King Abdul-Aziz international airport and classified the processing time among the most important measures affecting the users' observation of the level of service.

Produced survey has helped to generate performance measure upon passengers prospective. On the other hand a simulation model of the process flow is utilised to formulate driven data model of the terminal process flow operations. The model built on Arena software and correlation study is made from the multiple "what if" scenarios of the model. Then a linear regression is used to generate a model for each variable. Levenberg–Marquardt (LM) algorithm is used after to carry out better regression model then Neuro-Fuzzy (NF) model found to be more efficient as it is picked and used to generate a best observed prediction.

The system is optimised through the generated Neuro-Fuzzy (NF) logic model using both Particle Swarm Optimization (PSO) and Genetic Algorithm (GA). A validation in addition to the testing made in the optimisation system.

Analysis shows a great deal of improvement in predictions using fuzzy logic instead of linear regression for all dependent variables. PSO and GA optimisations are carried out and compared to the actual results gathered from the Arena simulation report.

Author's Declaration

I declare and certify the presented thesis is my own work never been submitted before and any support accessed and used has been acknowledged. I certify that all information sources and literature used are indicated in the thesis.

Signature

Acknowledgements

I express my deepest appreciation and thanks to Allah. I want to thank my supervisor Dr. Maysam Abbod who inspired me and guided me through the research journey in each step taken to whom I am grateful. I thank Dr. Ali Mousavi also for helping me during the DES modelling.

I have to write about the reason of being here my mother Wafa Banjer and my father Ghazi Gronfula who built everything I enjoy in my life today. Mohammed Ali Alireza you facilitated the first step to that journey. I express my thanks to all of my family members my wife Leena who supported me during my study, my lovely two sisters Azzah and Auhud and my brother Amin. I want to thank PPMDC especially Eng. Hesham Saeed for allowing me to carry out my research in their terminal operation environment.

I don't forget Abdulhafid Sallama who supported me with his knowledge. I thank the effort offered by Sandra Rawlin during my revision time and Hani Alharbi who helped to print my thesis in appropriate way. Lastly tanks to my dearests friends Saba Eshraghi, Ayidh Alanazi, Yahya Alshammari, Hezam Alsubaie, Mohammed Aleid, Mohammed Alqarni, Ayse Kulahli and Alaeddin Ghadamsi for the support they offered me.

Mohammed Gronfula, London, UK

Table of Contents

List of Figures

List of Tables

Chapter 1 Introduction

1.1 Introduction

Air travellers worldwide are facing several uncomfortable procedures in airports due to the heavy utilisation of the airports as well as for security reasons (siemens.com, 2011). Overcrowding in airports is not the only problem according to airport operators, as keeping up with improvements in the airport's set-up and actual development is a key interest.

Airport operation is one of the highly focused aspects of the airport terminal performance which is handled by the airport authority or operators. Some measures are stated to be a condition of continuation of handling the operation in the future given mostly by government aviation agencies such as GACA – the General Authority of Civil Aviation. On the other hand, some benchmarks (gaca.gov.sa n.d.) are set by the operator company or associated company to promote a high level of service, which can lead to operations in other airports, even internationally (e.g. Aéroports de Paris or ADP operates Marsa Alam International Airport in Marsa Alam, Egypt in addition to airports in France and other countries).

Performance studies in this area have mostly focused on two types of research: encounter experience that is observed by the client while the other is based on simulating the environment of the airport terminal. Both types have been considered in this research. High accuracy mathematical modelling is used to define a base to allow optimisation of the analysis. This can deliver a motive why the Hajj terminal in Saudi Arabia should be studied, since it is recognised to be the fourth biggest terminal with an area of 465,000 m^2 (aviation-safety.net, 2013; gc.kls2.com, 2006; worldaerodata.com, n.d.; siemens.com, 2011). Keeping the operation running efficiently involves cautious planning, which is the role of the airport operator according to the British Airports Authority (BAA) Operational Research group (modelco.net, n.d.).

1.2 Motivations

The development of measures for airport passenger terminals' operation has been one of the major issues for airport agencies for decades (Correia, 2008). This has motivated research by aviation related agencies, as well as the Federal Aviation Administration – FAA (Transportation Research Board, 1987; Airports Council International, 2000; Transport

Canada, 1979). The simulation itself has a high impact on decision making which is a motivation to adopt it as the key tool in this thesis (Hollocks, 1995).

However there is a limitation which motivated this research to facilitate a base to validate real time modelling like accurate arrival of planes on a certain time prior an event like Hajj or exact time consumed queuing time then performance measures that can be adopted in many contexts and incidents such as London Heathrow during the Olympics or the Hajj terminal during pilgrimage season. That can lead to predictions of performance by offering a model of optimisation systems for certain allocations and configurations of the airport terminal. Improving the passenger's flow process lead to have higher level of passenger satisfaction, which benefits airlines as client of the terminal operator who gains higher level of performance and reputation (see figure 1.1).

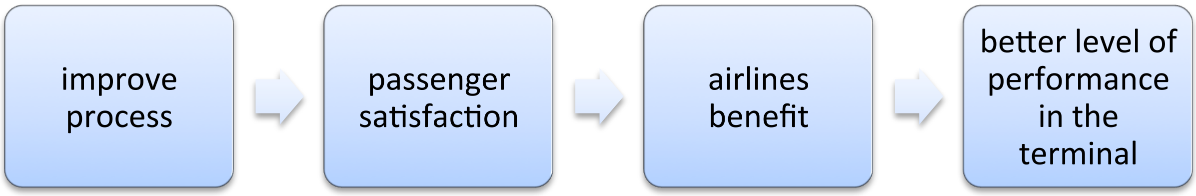


Figure 1.1 Research motivations

1.3 The Airport

The King Abdul-Aziz International Airport (KAIA) was the first international airport established in the Kingdom of Saudi Arabia. It is positioned north of Jeddah city in the west region of the Kingdom and contains four terminals (North, South, Hajj, and VIP). Initially, the North terminal operates flights of all international foreign airlines excluding flights in the Hajj period which are handled in the Hajj terminal. The South terminal is used by local airlines such as NAS and Saudi Arabian Airlines (see figure 1.2).

Figure 1.2 Hajj terminal with full 10 modules only five of them running (ppmdc.com.sa 2014).

The Hajj terminal has been handled by the Ports Projects Management & Development Company (PPMDC) on a Build, Transfer and Operate (B.T.O.) agreement with the General Authority of Civil Aviation for two decades, and it also covers five running modules. The five modules are colour coded and start from the aircraft PBB (Passengers Boarding Bridges) up to the passenger bus pick up area outside the terminal (V.V.), and for pilgrims the easy reference and guidance is illustrated in Figure 1.3.

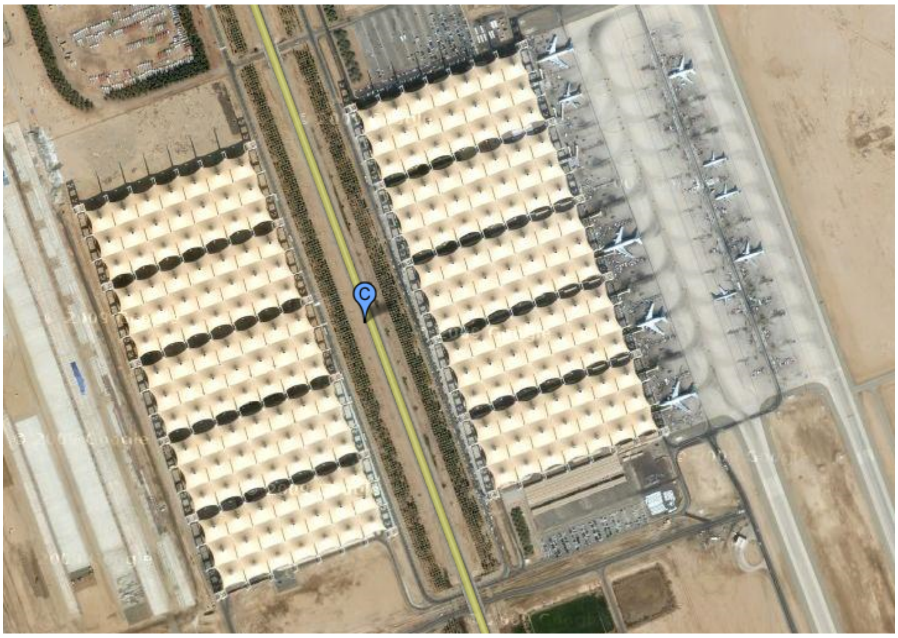


Figure 1.3 Google earth view of the Hajj terminal, showing the 5 running modules in the east portion of the Hajj terminal complex.

The east part of the Hajj complex holds five modules called A, B, C, D, and E. A total of ten PBBs (passengers' boarding bridges) connect the aircraft and alighted passengers to the ten passenger lounges positioned on the first floor of the terminal building. Moreover, four lounges are accessible on the ground floor for arriving/departing individuals conveyed by buses to/from the airplanes which are parked in remote areas. Module C (ground floor) is reserved for controlling the check-in of departing individuals and is well-appointed with 58 check-in counters and a baggage handling system (BHS).

Furthermore, ten baggage conveyer belts, with movable check-in counters, are accessible in modules A, B, D and E (20 counters at each module). The ten belts are used for both departure and arrival baggage, but the check-in counters are utilised only for departure processing. The terminal has 114 passport checking counters which are spread over four sites, with the capabilities of (48, 48, 18, and 18 counters) presented in Figure 1.4. Sixteen customs counters are located at the exit of the four modules A, B, D and E (four check points at each location) (Gronfula, 2009).

Figure 1.4 Ground floor of the Hajj terminal shows the five different modules (ppmdc.com.sa 2014).

The jet-parking apron at the complex holds ten parking inlets with ten PBB which will attach the airplane with the ten lounges positioned on the first floor of the terminal (as shown in Figure 1.5). The jet-ways and lounges are secured and managed by the Royal Saudi Air Force (R.S.A.F).

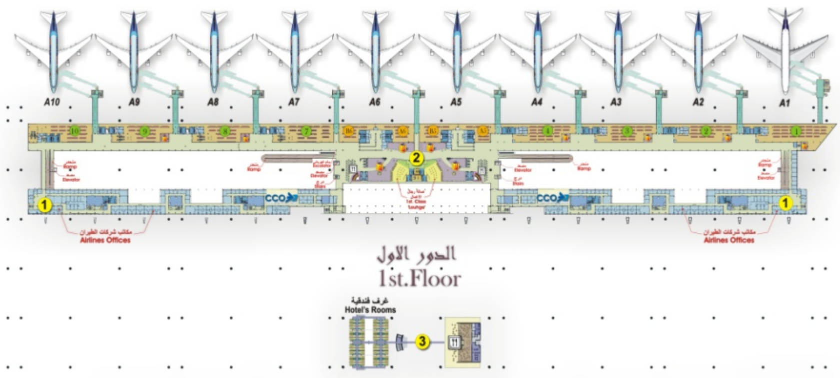


Figure 1.5 First floor in Hajj terminal and its jet-ways and lounges (ppmdc.com.sa 2014).

1.3.1 The Passenger Flow

There are two passenger flow process structures, the first is arrival passenger flow and the second is for departure. Contrasting with any other terminal, this terminal has two entirely distinguished stages; the first utilises only the arrival structure (named the arrival phase) and begins a month prior the Hajj, which is defined by the Hijri Islamic lunar calendar.

Yearly, the Saudi government distributes a circular to all airlines declaring the 8th of Dhu al-Hijjah month as the last day of this stage. After Hajj is performed which usually takes four days, the departure period begins. These four days act as a switch-over period where the airport terminal arranges all of their required modifications and prepares for the departure phase, with planning and considering all the factors which have an impact on the flow (Gronfula, 2009).

1.3.2 Passenger Process Flow and Airport Operation

Passenger flow can be described by looking at the daily operations which occur in the busiest terminals, with about 100,000 movements registered during summer days, which means an aircraft takes off or lands every half a minute. After the gate opening announcement of a flight by its number, a family organise their belongings and make their way to the gate. In another part of the airport, a group of travellers from a school arrive at the terminal and wait at the passport check points to have their passports stamped. In a different place, a woman gathers her bag from baggage claim and checks it in customs. As mentioned before, this is a role for the terminal operators to manage or perform. For example, BAA owns and functions seven airports in Britain: Heathrow, Edinburgh, Aberdeen, Glasgow, Gatwick, Stansted, and Southampton, as well as Naples International Airport in Italy and three terminals in the states: Baltimore-Washington Airport, Boston (Logan) Airport, and Pittsburgh Airport (heathrowairport.com, n.d.). Aéroports de Paris on the other hand is the airport authority that owns and operates the 14 airports and airfields in France (aeroportsdeparis.fr, n.d.). Fraport AG is another significant enterprise which processes Frankfurt International Airport and has shares in 11 other international airport's terminals, and a couple of these are in the Kingdom of Saudi Arabia (fraport.com, n.d.).

1.3.3 Airport Operator Companies

BAA classifies itself by saying "We operate our airports in a way that seeks to meet the needs of passengers and airlines while at the same time providing an appropriate return on investment" – a description which has three main parts: 1) airport amenities, 2) different passengers' requirements, and 3) air carriers (heathrowairport.com, n.d.).

1.3.4 PPMDC Operations

New expertise and processes are deployed to service Hajj and the travellers who land at the Hajj terminal in KAIA, from the time they reach the jet-bridge to the baggage claim area using visual guidance structure, by utilising a well-defined flight information system.

1.3.5 Vision

PPMDC has the vision "To become the leading port management and development company in the region while managing the flow of people smoothly and with exceptional service, always insuring both their safety and comfort " (ppmdc.com.sa, 2014).

1.3.6 Mission

"PPMDC will establish benchmarks for border ports, seaports and airports by establishing first rate services and operational excellence to ensure all people and cargo move smoothly. This will be done through our professional team expertise and partnerships with all stakeholders to meet and exceed all requirements and expectations (ppmdc.com.sa, 2014)".

The PPMDC was introduced as the first in Saudi airport operation with French experience, which was grown from their associates Aéroports de Paris who qualified all PPMDC employees in the initial phases when the company was established. Since 2007, PPMDC earned a 20 year managing contract of the Hajj terminal as part of the Saudi privatization strategy to guarantee an enhanced level of service and found a new standard of customer orientation in that specific field. The training contained two parts: managerial and key operational jobs.

The company, exposed to such distinctive practices as the Hajj terminal, has a unique passenger flow unlike any other international airport terminals, and was designed by engineer M. Othman, the CEO of PPMDC. The administration of the company includes twelve officers who started to gain knowledge over how to run such a terminal devoted for Hajj. The scheme that the company proposed is centred on visual contact and guidance for travellers "hajjis"; therefore, with passengers with diverse nationalities and speaking diverse languages, the simplest approach is to lead them through using colours; each starts from the beginning of their journey until the end as illustrated in figure 1.6.

Figure 1.6 The design that the company is offering, based on visual contact and guidance for passengers through different colours (ppmdc.com.sa 2014).

This terminal can accommodate ten aircraft simultaneously through utilisation of jet-ways which are compatible with the new Airbus 380. In addition to that, the PPMDC has a Build Transfer Operate (BTO) contract with the Government.

1.3.7 PPMDC standards

Standards have been assigned to guarantee a sustainable investment that will benefit all concerned by enhancing the level of service with high utilization by several associations, and those are:

- **King Abdul-Aziz International Airport (KAIA)**

King Abdul-Aziz International Airport Authority belongs to GACA and is accountable for all terminal services delegated to operators, to improve the function of the airport facilities.

- **General Authority of Civil Aviation (GACA)**

The GACA is a governmental sector which is accountable for managing many tasks and duties in the aviation domain, air carriers and airports, such as configuring, supervising, functioning, and sustaining the civil airfields in Saudi Arabia. Likewise, they need to manage the air navigation system, and support it with the appropriate navigational systems.

- **The Saudi Arabian General Investment Authority (SAGIA)**

SAGIA is responsible for administration of any investment in the Kingdom. Its objective is to attain a sustainable economic development by generating a pro-business environment, delivering essential services to investors, and elaborating investment opportunities in significant segments of the economy, including energy, transportation, and ICT.

- **International Finance Corporation (IFC)**

This is the world's biggest multilateral source of finance for private sector projects in developing nations. It serves to back supportable private investment in developing countries in order to develop human's lives. The IFC is one of the associations of the World Bank Group and its headquarters are located in Washington D.C.

1.4 Aim and Objectives

The aim of this thesis is to develop an optimisation system to improve the performance of airport terminal operations.

In order to achieve this aim, a simulation model of the airport is developed which is used to test different optimisation regimes and scenarios. The objectives appointed to develop a model of the airport are defined as follows:

1. Literature and state of the art of terminal performance development by looking at level of service assessment in the aviation field and simulation methodologies.
2. Develop a survey questionnaire to allow LOS assessment of the airport terminal.
3. Collect data from both ends: passengers and the airport operator, either from a data sheet or from the survey carried out.
4. Analyse the data using mathematical techniques (e.g. correlation, linear regression and LM algorithm) and computer programming (e.g. MATLAB, SPSS, optimtool and neuro fuzzy logic NF).
5. Develop a Discrete Event Simulation DES model using Arena or other software, which allocates resources and generates time observations.
6. Develop a data driven model, test different models and elect the best.
7. Validate the model.

8. Develop an optimiser; different types are examined (e.g. GA and PSO).
9. Test the system.
10. Create a model that can predict the airport capacity in order for its operational efficiency to be optimised.

1.5 Research Methodology

The aim of this research is to assess terminal operation performance and create a system that measures and evaluates airport terminal operations. This can be achieved by building 'know how' to develop formulations of the measure to allow ranking the LOS in the airport terminal and that can be done by software applications like SPSS and MATLAB using optimisation techniques and a discrete event simulation (DES) model. The first steps are to extract factors that help to assess the airport LOS that has been used before conducting a survey in the Hajj terminal of King Abdul-Aziz Airport. Interviews are conducted to gather the operator aspect of performance. Data sheets are scrutinised to grasp the essential input feeds of the DES model. The DES model is designed and tested considering controllability which allows varying inputs. Inputs and observed outputs and identified then included in the Arena generated report. Then the numbers of trial groups are addressed in order to carry out analyses. Correlation is allocated to identify the significance of factors' relations. Regression is carried out in a linear form, as well as non-linear models, using data driven modelling techniques such as Neuro Fuzzy (NF) modelling. Comparison of the linear regression model with the NF model is carried out. The models are tested and validated, then utilised to carry out the optimisation. Heuristic optimisation techniques are used such as Particle Swarm Optimisation (PSO) and Genetic Algorithm (GA). Lastly verification is carried out in the DES model.

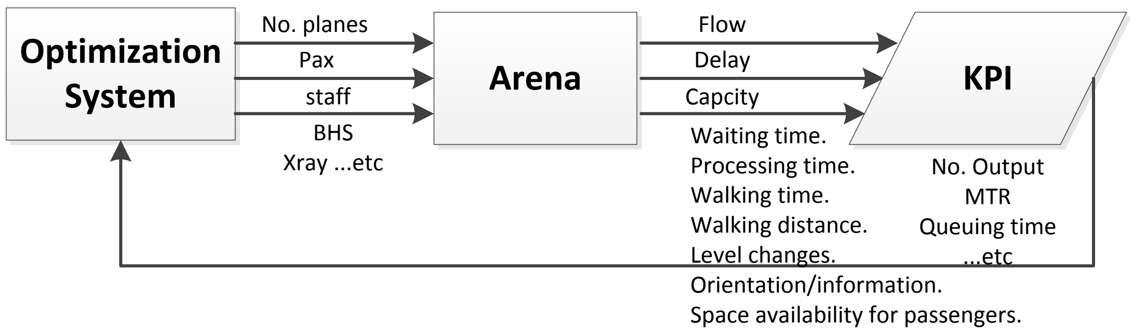


Figure 1.7 Research conceptual framework

1.6 Challenges

Developing an accurate model of the airport can be challenging; the challenges can be stated as follows:

- Data collection (access to the data) - which to be captured? to what extent? There are challenges relating to data collection, such as the fact that airport information is treated as secretive information and the survey needed to be authorised by the Ports Projects Management & Development Company (PPMDC), General Authority of Civil Aviation (GACA) and King Abdul-Aziz airport authorities.
- Timing as it requires going at Hajj period to study the context and the process during the terminal utilized time.
- Model developments (some software limitations) design logic flowchart. DES modelling design as it is time consuming, and was used following guidance from my supervisors, utilising simulation course materials. DES model execution time is long and from that a sample of about 500 trials was agreed to be covered, about half of them executed in an ordinary manner.
- Factors identification which is encountered in the research.
- Data driven model methodology, accuracy, validation (methods should be criticised). Challenges regarding regression as linear and LM regression models considered to be insufficient. NF helped to carry out a better representation of the model. Challenges related to NF model identified by looking to the surface of the created model and adding some trials.
- Optimisation techniques (required techniques investigation and deployment) and their behaviour; points can be dragged to an undefined space or unrealistic range and that is overcome by defining an optimisation range. In addition, there are challenges related to the cost function which can be solved by carrying out normalisation using the trials' sample.

1.7 Contributions to Knowledge

There are many LOS evaluation, DES modelling, NF modelling and optimisations, yet what is significant about this research is the integrated system that leads to early investigation and inspection of any implementation related to the process.

The uniqueness can be seen by combining both ends of the process in the evaluation to carry out the performance measure. This will facilitate many other developments in real time simulations and optimisation of the operation performance measure. The field can incorporate a holistic approach as a new benchmark of LOS as presented by Correia (2008). The developed optimisation system is applicable and beneficial for any airport terminal with any configuration settings. In addition to that, this can be used with slight modification in any transportation station. This research's contributions are summarised in the following points:

- Studies on airport terminal performance exposed and identified by both customers perceived terminal experience and terminal simulation by carrying literature review in that area.
- A survey is carried out in the airport terminal to measure LOS based on passenger's perceived experience right after their journey in the airport.
- Development of controllable self-built DES simulation model with capability of changing assigned inputs easily.
- Identification of effective factors used on airport terminal performance through the survey and DES model.
- Development of linear regression model to predict and estimate an output for any valid input values related to the airport operation.
- Development of LM regression model to carry out predictions as it may carry a better estimation level.
- Development of neuro fuzzy logic model for each variable to compare and achieve best estimation among other used methodologies.
- Optimisation to passenger flow process flow is done with PSO algorithm, which generates normalisation function in order to allow values to be used in generated cost function.
- Optimisation to passenger flow process flow is offered by using GA algorithm.

1.8 Thesis Outline

The proposed thesis consists of eight chapters as illustrated in figure 1.8, the first of which contains the introduction, motivation, airport description, aims and objectives, challenges, contributions and the thesis outline.

The second chapter presents the literature review related to the study with nine sections. This lays out studies carried out on airport terminal performance evaluation by both approaches of customer perceived terminal experience and terminal simulation.

The third chapter describes of the tools and techniques utilised in the research with eleven sections. It starts with revealing descriptions of software such as Arena, SPSS and MATLAB, then modelling algorithms: Correlation, Bivariate Correlation, and Linear regression, The Levenberg-Marquardt Algorithm and Neuro-Fuzzy Model. Finally, it ends with optimisation techniques: Genetic Algorithms and The Particle Swarm Optimisation.

The fourth chapter deals with the Airport Survey which illustrates the survey which conducted in the airport terminal. The chapter produces LOS assessments at the airport terminal considering user experience. That enabled a discrete event simulation that focuses on the processing time of each resource, which is found in chapter 5.

The fifth chapter presents the Simulation Model where the DES model input is revealed and prepared along with model logic construction as blocks of modules. The main aim of the created simulation model is to obtain the results needed for the next step of the project, which considers various simulation scenarios' inputs and presents their input-output analysis.

The sixth chapter presents gathered results in groups of trials with a description of the findings. It starts with a brief description of the input data, each group is presented in detail with charts of some dependent variables along with the varied variable.

The seventh chapter contains Optimisation and Results Analysis where multiple modelling algorithms are addressed then optimisation techniques utilised and the results validated.

Finally, the conclusion and future work are presented in the last chapter.

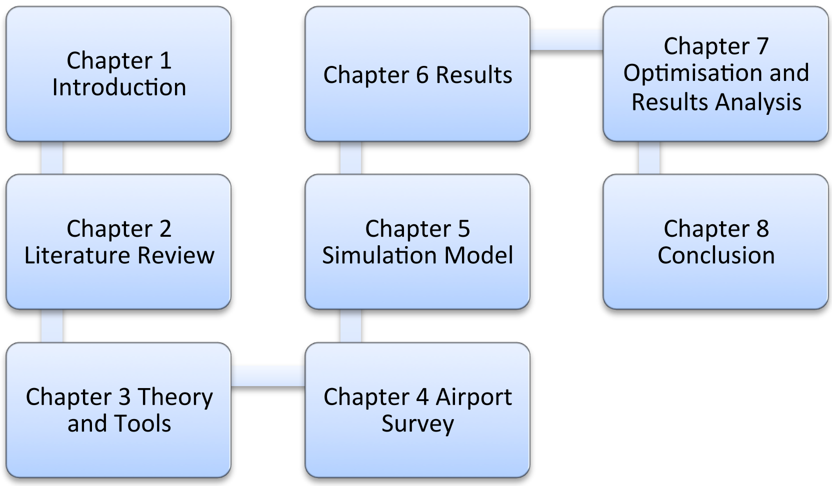


Figure 1.8 Thesis chapter outline.

Chapter 2 Literature Review

2.1 Airport Level of service

A number of studies on the development of the level of service (LOS) have been conducted by agencies are related to aviation or air transportation industry, including the Federal Aviation Administration – (FAA), as it is one of the key issues in the aviation industry over the last few decades (Transportation Research Board, 1987; Airports Council International, 2000; Transport Canada, 1979). Correia and Wirasinghe (2004) claimed that while LOS has been evaluated at individual airports, there is no standard method or reporting system for LOS evaluation. They established measures to evaluate the LOS at airport passenger terminals of interest to airlines and airport operators. In addition to that they presented a review of the past research on LOS.

Graphical displays were constructed by Mumayiz and Ashford (1986) based on passenger responses concerning the LOS provided at airports in England, and used to propose their concept on perception response. Omer and Khan (1988) engaged the concept of utility theory to build up a link between characteristics of facilities (e.g., waiting time, space available) and user responses (0–1) about the LOS. Müller and Gosling (1991) utilised a framework that employed a psychometric scaling technique to obtain a quantitative measure of LOS that could be used in a relationship similar to the methodology of Omer and Khan (1988). They argued that it is essential to reflect on the perception of the users of the terminal and permit the assessment of many different criteria on a single value scale to make rational decisions.

Airport LOS measuring standards were developed for several components of the airport passenger terminal based on a personal interview survey of departing passengers by Seneviratne and Martel (1991). According to Seneviratne and Martel (1991), the variables that have a significant influence on the performance of a particular element of the terminal are quite different to those influencing the performance of another element. Their selection of the most important components and measures was based on a survey of Canadian airports.

The standard examination of administration quality has been dependent upon the thought that the quality level of administration is discerned and assessed by clients (Gronroos 1990). The most generally utilized client recognized administration quality model is probably the Gap Analysis and SERVQUAL model that measures the scale of Quality in the service sectors by

Parasuraman et al. (1985, 1988). Notwithstanding its approval in thought, this model might have natural issues in measuring client requirements of LOS quality. Gronroos (1993) accordingly infers that measuring clients' opinion of service quality, in delivering a nearby estimate, is a hypothetically legitimate method for measuring observed quality. In practice, this shortens the procedure of data gathering and classification by reviewing the feedback.

Essentially, service experience opinions are observations of realism, in which prior prospects are inherent. This idea is in accordance with the studies that conduct research by using clients' mentality as an overall assessment of a product or service. Clients' viewpoints towards a service rely upon (first) the quality of their confidence in different characteristics or qualities connected with the service and (second) the weight of attributes (Engel et al. 1995). Clients' convictions ordinarily include observed relations between the service and its related properties, obtained from their immediate experiences with the service. The relative importance is offered as a weight of the attributes, as it is perceived by clients.

A client's opinion towards a given service is based on the summation of beliefs about the service's characteristics weighted by the significance of these characteristics as devised in the Fishbein's attitude model (Fishbein and Ajzen, 1975). This aspect concurs with MADM models dependent upon "multiattribute value theory" (MAVT) (Dyer and Sarin 1979; Keeney and Raiffa 1993). MAVT-based MADM is generally used to evaluate a limited set of various substitute choices and options, typically with conflicting criteria (Dyer et al., 1992; Hwang and Yoon, 1981; Stewart, 1992; Yeh et al., 1999). The performance of an airport passenger terminal can be identified from the perspectives of travellers, carriers, and the runway specialist (Lemer 1992).

2.2 Terminal and Modelling

The area of runway terminal modelling and execution evaluation has pulled in considerable exploration in the most recent two decades. An assortment of models and instruments shedding light on airfield terminal choice has been produced with the specific purpose of expediting choices in creating runway terminal designs, and arranging operations' administration (Mumayiz, 1990; Odoni, 1991; Odoni and de Neufville, 1992; Tosic, 1992; Trb, 2000a).

2.3 Data Envelopment Analysis

Data Envelopment Analysis or DEA models are used for decision making in business to analyse efficiency. One of this tool's advantages is that the input of the simulation does not need any change to real process and cost of affecting the running process is low; in addition to that it is non-parametric. Therefore it is a suggested method for estimating the relation and the weight between inputs and output. Farrell (1957) is known to be first who presented an estimated measure factor to reflect an organization's efficiency; although this approach was not welcomed at that time (Charnes et al. 1978). Cooper et al. (2007), Zhu (2009) and Avkiran (2006) have explained the details of this approach. Liu et al. (2009) present a standardization strategy, which makes urgent changes to the previous best method by increasing discrimination in data envelopment analysis.

Furthermore, various models have demonstrated that point and given help in the assessment of the execution of the terminal procedure framework, or parts of it. As well as the level of administration recognized and identified via airstrip clients (Andreatta et al., 1999; Correia et al., 2008; Lemer, 1992; Trb, 2000a). Adler & Berechman (2001) have distinguished between two types of data: 'subjective' data and 'objective' data during their model development to analyse the relation between the efficiency and the quality of airports. Their statistical analysis of the median score has shown that these estimations vary significantly relative to the quality factors and airports that they have studied.

Two data envelopment analysis (DEA) models have been developed by Gillen and Lall (1997) based on terminal and airside operations. First they have used the number of runways, employees, gates, baggage collection belts, public parking spots, and terminal area to calculate the number of passengers and amount of cargo. The second model uses the number of runways, employees' airport area, and runway area to describe air carrier and commuter movements. Liu and Lu (2010) have introduced a network-based approach with a ranking model of DEA as an R&D case for performance. Their novel method intended to increase discrimination at DEA by enhancing the network-based approach. They claim ownership of the centrality concept development in social network analysis brought by implementation of that approach (see Figure 2.1).

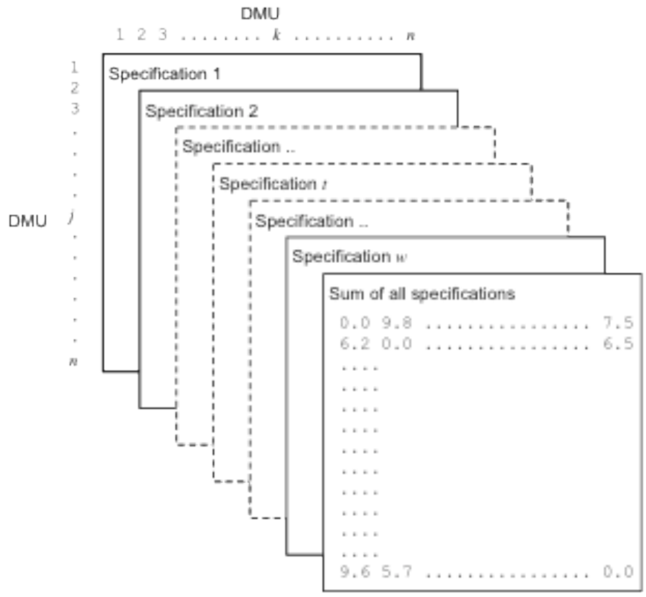


Figure 2. 1 network-based approach with ranking model of DEA (Liu and Lu 2010)

2.4 Airport Simulation Modelling

Simulation Modelling is the practice of building and analysing a prototype of a actual model to predict its performance in the reality (Sharma, 2008). One unanticipated passenger flow simulation-based research reform based on the work was carried out by Chung and Nyakman (1996) as it was considering security as important measure which was still unknown yet in that extend and it had been progressed and delivered after. The research was solely concerned with the operation of security staff, explicitly, the checkpoints, under expanded danger conditions. They have examined the preparing of travellers through security checkpoints at major metropolitan airports, and their findings offered a path to authorities for maintaining a satisfactory traveller improvement under these high-risk conditions. A simulation examination was performed to survey this setup and a few situations were produced to deliver the best mode of operation under a mixed block of elective setups (Chung and Nyakman 1996).

After that, a range of papers has illustrated the use of simulations to check the robustness of flying schedules: (Beck, 2004; Fan et al., 2004; Fayez et al., 2008; Klempert and Wikenhauser, 2008; Herbers, 2008). Mitra (2004) focused on how airline operational performance could be improved by the use of simulation to study the robustness of aircraft flying lines of work and airport schedules. Additionally, the centre of commercial passenger flow research has been considered as a method by including the passenger flow procedure of existing airport terminal layouts. The utilization of simulation models has been one of the prevalent methods (Fayez et al., 2011).

Gatersleben and Weij (1999) exhibited a dynamic simulation model utilized as a part of the restructure and classification of air traveller care at airports. The aim was to apply a simulation to explain the link that exists between passenger flow and the procedures attached to it, the presence of bottlenecks, and conceivable results. Their dynamic simulation model has examined and assessed, during improvement of situations, passenger flow all through the terminal and the use of non-assignable facilities, while recognizing their reliance.

Valentin (2002) confirmed the significance of adopting simulation models at airports where operations are liable to alteration and bottlenecks. A reproduction apparatus framed as a set of building pieces in a simulation model was utilized to help the modelling of airports. The paper gave a short idea of the building blocks, their utilization in the simulation scenarios of passenger streams and the effects of the simulation scenarios utilizing these building blocks. Valentin declared that however a terminal is configured; the configuration remains a centre of attention. Security and safety can likewise be determined by utilizing simulations.

A comprehensive survey of literature was presented for both methods of ranking and selection (R&S) and multiple comparison procedures (MCPs), stressing the importance of simulation assessment of alternative designs without any physical cost (Swisher, 2003).

Olaru and Emery (2007) have utilized simulation models and genetic algorithm (GA) optimization to model the operation of traveller terminals. This model was utilized as a procedure of organizational change to assess the productivity and execution of the airfield operation, and the effects of framework and operational changes.

Beck (2011) offered a case study on how a simulation model that simulates passenger flows in an airport terminal was used prior to and after the Heathrow Terminal 5 opening. He discussed some of the factors that had to be considered when creating the model. Beck (2011) made his model the core of the decision making process and has used it in a number of different scenarios since it was generated.

The use of simulation within aircraft and airline engineering has been expressed in Bazargan and McGrath (2003), Crocker and Sheng (2008) and Mattila et al. (2003). On the other hand simulation has also been used to examine different boarding strategies for the Airbus A380 aircraft (Bazargan et al., 2008). Tug operations at airports were focused on by Bazargan et al. (2008) to describe how simulations can be used for that function. Verbraeck and Valentin (2002) offered an approach to create a reusable simulation building block and use that as tool to resolve many questions to enhance and accelerate creation of such models using the simulation language eM-Plant.

The level of influence of building on the wind field patterns can be measured by carrying out qualitative and quantitative treatment of the results gathered from Three-dimensional Computational Fluid Dynamics simulations (3D CFD). Specific attention is paid to the research of the effects of building on the in-flight conditions over the area close to the airport runway (Neofytou et al., 2006). Capacity and delays in airport passenger terminals can be measured and estimated by Simple Landside Aggregate Model (SLAM) (Brunetta et al., 1999). A series of “what if” scenarios from the simulation model can generate mathematical formulation LOS.

Takakuwa and Oyama (2003) offered a passenger flow simulation in an entire airport terminal building and their focus was on the international departures. They claim that check-in time is over 80% of the whole waiting time in the terminal. The simulation model was developed and built using a special purpose data generator. They suggest that economy and group class passengers should utilize the first and business class check-in counters. They generated an exploratory data for executing a simulation by outlining and advancing a special-purpose data-generator. Based on that concept, the likely number of postponed flights is surely narrowed by expanding terminal support staff and additionally by utilizing first and business class check-in counters to also process economy and group class travellers.

2.5 Discrete Event Simulation and Optimisation

The historical Discrete Event Simulation (DES) was reviewed as it has been known as a famous modelling tool since the 1950s when computer simulation was invented. Since 1990 a lot of developments have taken place in modelling. There has been a lack of development in simulation, compared with the advanced developments in computing, as criticised by Robinson (2005). DES is used to model the operation of a framework or a system as a discrete arrangement of occasions in time. Every occasion happens at a specific moment in time and marks a state change in the framework (Robinson, 2004).

Glynn (1990) defined two main issues that motivate research on “efficient gradient estimation algorithms”. He gave a quite general set of “efficient gradient estimation algorithms”. Then he derived an estimator for discrete-time simulation in both cases of time-homogeneous and non-time homogeneous discrete-time Markov chains. After that he applied that in continuous time. Finally he concluded with a discussion on essential matters that occur in adopting the “likelihood ratio gradient estimator” as a measure of steady-state performance. Simulation was employed to optimise the behaviour of discrete event systems by demonstrating a generic framework for that as a general state space Markov chain. Andradóttir (1996) adopted the “likelihood ratio gradient estimator” to obtain performance measures by taking into consideration Markov chains in different senses (Andradóttir, 1996).

Swisher et al. (2003, 2004) conducted a review of discrete-event simulation optimization advances and detected a significant interest in extracting useful information about discrete-event simulation model of an actual (or yet to be designed) system. Swisher et al. (2003) used ranking, selection and multiple comparison procedures and Swisher et al. (2004) concentrated on discrete input parameter optimization. Passenger boarding time was focused on and required re-engineering projects. Van Landeghem and Beuselinck’s (2002) results indicated that there is a gap between the practiced process and an optimal model.

Alrefaei and Andradóttir (2001) thought about obtaining a “global optimal solution” using a modified stochastic ruler method as the number of visits this sequence makes to the different states to estimate that optimal solution for a discrete optimisation problem. A survey of issues specific to simulation optimization was offered by presenting a reasonable overview of the field with some of the methods and techniques (Azadivar 1999). It stressed the importance of both mathematical and simulation modelling awareness to carry out a valid simulation optimisation. Simulation optimization literature was reviewed comprehensively by Glynn (1986), Meketon (1987), Jacobson and Schruben (1989), Safizadeh (1990) and Andradottir (1998). Andradottir (1998) offered a simulation optimisation methods review with the focus on gradient-based techniques with optimisation according to continuous decision parameters and on random search methods with optimisation according to discrete decision parameters.

2.6 Performance

Many literature was found for the case of measuring number of random variables' effect on performance of interest then "expressing this performance measure as an integral involving the product of densities of the underlying random variables" is involved by likelihood ratio method as it is explained by Glynn (1990), Rubinstein and Shapiro (1993), Andrad6ttir (1996b). Nwofia and Chung (2013) have covered the performance of airport security using simulations as they observed the arrival of new security measures at complex and congested airports. This is presented as a tool to assist airport design with what they called "intelligent design concepts", which can be premeasured along with usual existing operational performance and passenger flow factors.

Based on their usage Wu and Mengersen (2013) categorised existing airports models into four categories "1) capacity planning, 2) operational planning and design, 3) security policy and planning, and 4) airport performance review". They built up a framework based on a Concept of Operations (CONOPS) to examine the ability of modelling enhancement. Personnel scheduling was used in Mason et al.'s (1998) model of customs staff in an international airport in New Zealand. It accomplished an integration of the usage of simulation, heuristic descent, and programming to optimise staffing in that area. Mason et al. (1998) targeted the balance between high quality in passenger processing and low staffing for a higher level of performance.

Mumayiz (1991) presented a concept for the assessment of quality of service at airport terminal facilities by measuring passengers' opinions, their observation and satisfaction. Determining levels of service for airport facilities can be achieved by using this method for the system service performance measures combined with capacity assessment techniques like simulation. The use of DEA was studied in three types of airports to help airport authorities to determine efficient future growth (Yu 2004). These airport efficiency measures criticized using output-oriented data envelopment analysis (DEA). The study took place in Taiwan and Yu (2004) argues, "Expanding facilities at some of the domestic airports in Taiwan may not be necessary". Yu (2010) presented a SBM-NDEA model to measure airport performance under series productions with quasi-fixed inputs of the runway. His study estimates the input and output deficiencies with respect to production and service processes, respectively. The measurement is based on the assumption that "airport operations efficiency is decomposed into production and service efficiency".

Oum et al. (2003) produced an efficiency comparison in major airports worldwide (total of 50 airports in Asia Pacific, Europe and North America) by looking at total factor productivity (TFP) which is a measure of the impact on total output not produced by traditionally considered inputs of capital and labour. This led them to TFP analysis using some regression models. Their findings uncover the fact that a higher gross TFP can be predicted from larger airports. They also state that a higher TFP level can be found in airports with capacity constraints which will besides cause high delays for aircraft and passengers.

A cost analysis study was offered that can find out the cost effectiveness of the minimum total costs by "airport gate position estimation". As Wirasinghe and Bandara (1990) presented, a limitation of the number of available gates can cause delays to flights which can be treated as an added cost to the operation. This can be worked out by knowing the arrival rate. Their study took place at Calgary International Airport, based on a common gate use policy.

Humphreys and Francis (2000) have produced a critical approach to review traditional airport performance indicators. Their review of airport performance measurement was conducted in various ownership patterns from Europe and the United States, taking into consideration different practices. The emphasis was on evaluating airports' performance objectively by the study of the need for airports to be aware of their contingent circumstances.

Systems integration capabilities and barriers in addition to stressing on adopting megaproject management to achieve better performance in organizations' projects have been pointed out. Davies et al. (2009) have developed a conceptual model to help organizations that struggle to beat the poor performance found in many megaprojects. The study concludes that organisations should overcome relationships and behaviours by changing resistance in construction and project management areas. The study took place in London Heathrow Airport terminal 5. Caldwell et al. (2009) have created an airport performance factor that is concerned with the complex procurement activities related to London Heathrow Terminal 5. That kind of factor affects "multiple dependent interactions between many stakeholders over time". They have concluded that there is a need for contracting mechanisms, and new techniques and approaches yet may face resistance to change.

A study of airports' performance measurement was made where past, present and future measures were considered in Humphreys and Francis's (2002) model. The importance of the measure was observed clearly in "day to day" based operations. Parties that were involved in such measures are listed as: 1) business and operational management, 2) regulatory bodies, 3) Government and 4) other stakeholders. Changing organizational contexts was the main reason behind driving developments to measurement systems. Francis et al. (2002) have offered a survey of 200 of the busiest passenger airports in aspect of benchmarking airport performance. They have included a discussion regarding the nature, prevalence and consequences of such benchmarking in such an environment. They have concluded Best Practice Benchmarking characteristics and relevance by reviewing airport benchmarking literature.

Performance assessment done in current models of airport terminals need an extensive modelling effort to represent and mirror effectively different airport operational policies embraced in a user-friendly way (Manataki and Zografos, 2010). For that reason, there is a call for building up a common flexible "decision-support tool" to assist "high-level decision-making" associated with essential modifications in the configuration and process of the airport terminal system. Multiple airport terminal check-in techniques have been examined and studied by many self-service scenarios (Abdelaziz et al., 2010). Efficiency and performance are claimed to be enhanced by the use of self-service technology. Their prepared model embraces available applications of self-service technology in the international airport environment. Cost cutting is another aspect of the study's concern.

The fuzzy multiple-criteria decision-making method compares and assesses 14 international airports in the Asia-Pacific region (Yeh and Kuo 2003). The degree of optimality is taken into account as the centre of the research. One global service performance key every airport is acquired by integrating the leaders' certainty or confidence level and preference in fuzzy evaluations of the results. The method offers a helpful choice as performance assessment of airport services that handles subjective considerations of qualitative characteristics. The key assists the airports in recognizing their status in terms of controllable passenger service quality.

2.7 Airport planning

Configuration of an airport terminal can be determined by considering passenger-walking distance (Bandara and Wirasinghe, 1992). It's aim is to achieve minimal mean walking distance for all the passengers. A report is made of several statistical factors that aims to evaluate the optimum measurements for different designs. Concerning passenger walking for a wide range of passenger mixes and numbers of gates, it has appeared that the best terminal configuration is a semi-centralized pier configuration (Bandara and Wirasinghe, 1992). Jim and Chang (1998) have presented a SAM II simulation model that simulates Singapore Changi Airport. Their approach has been verified, compared, tested and validated with the data they extracted from the airport. "The animation is presented on a facility diagram which graphically portrays the layout of the passenger terminal". They argue that passenger terminal design has not yet been covered and more research should be conducted in that area.

Estimating and assigning a suitable space for every activity (or resource) wrongly in a way that has unsatisfactory results can lead to "expensive errors" (Odoni and de Neufville 1992). The nature of the process is a fundamental issue, to be precise, the area per passenger formulas in different parts of the building. These formulas are inconsiderate to variation of both operation and traffic in aspects of nature and characteristics. Odoni and de Neufville (1992) offered a considerate study based on the theory and experience internationally at major airports to produce practical procedures for terminal design. Their approach introduces automated models of the performance of terminals, which answer "what-if" questions rapidly in a spreadsheet form.

The civil engineering performance perspective is considered also in simulation modelling especially in areas of planning, design and operations. There is comprehension that choices made concerning terminal arrangement, outline and operations involve critical trade-offs with respect to elective operational strategies and physical terminal layout thoughts. Manataki and Zografos (2009) advanced a mesoscopic model for terminal execution dissection that uncovers a compromise between adaptability and practical effects, receiving a framework progress approach. Current modelling is found to be either too "detailed" or too "aggregate" and an approach of knowing the right level of details is needed, as discussed by Manataki and Zografos's (2009) model. This concept claims to bridge the gap between macroscopic and microscopic modelling by trying to hit the balance between flexibility and realistic results.

The approach was tested and validated in Athens International Airport terminal. This approach expedited model advancement by being versatile to distinctive airfield terminal setups and operational qualities (see Figure 2.2). As mentioned in Wu and Mengersen's (2013) study, there are new efforts to establish safety factors in light of worldwide security concerns, and more airports consider worldwide measures to look for new innovations in their methodology in designing airfield outlines, arrangements and operations (Fayez et al., 2008; Azad and Tokhi, 2007).

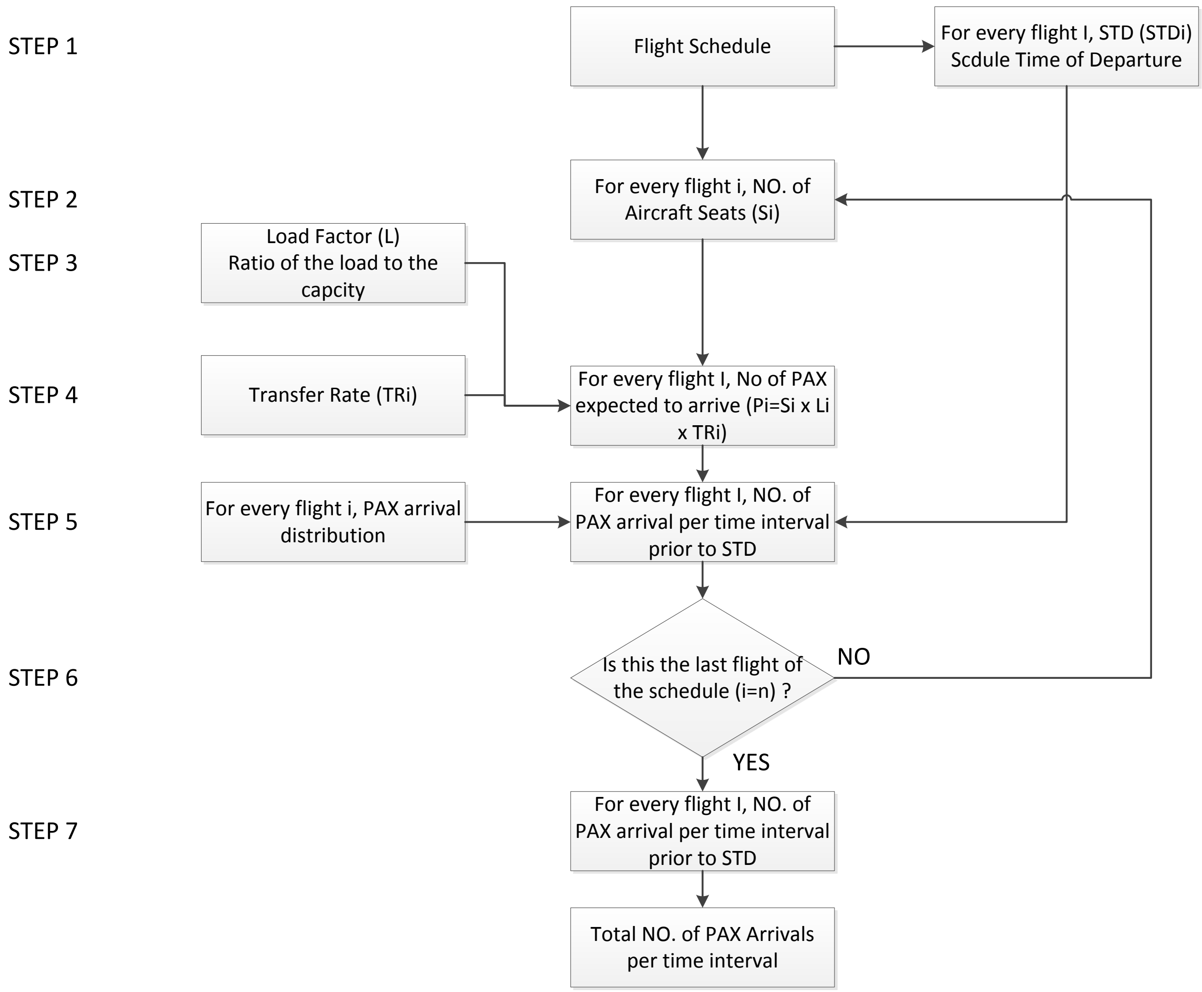


Figure 2.2 Modelling passenger arrivals at the airport terminal (Manataki and Zografos, 2009).

2.8 Airport Mathematical Analysis

A research results review has been carried out in the area of airport passenger terminal operations modelling and analysis with available information about software application, techniques and methods (Tošić, 1992). Journals and publications were criticized as a source of that review. Baron (1969) presented one of oldest pieces of research that was directed towards providing better access to airports. He offered a simulation analysis of airport terminal operations. Baron (1969) concluded that the analysis of typical terminal designs cannot be claimed to be comprehensive, essentially because no weighting factors were used and there are some restrictions (see Figure 2.3).

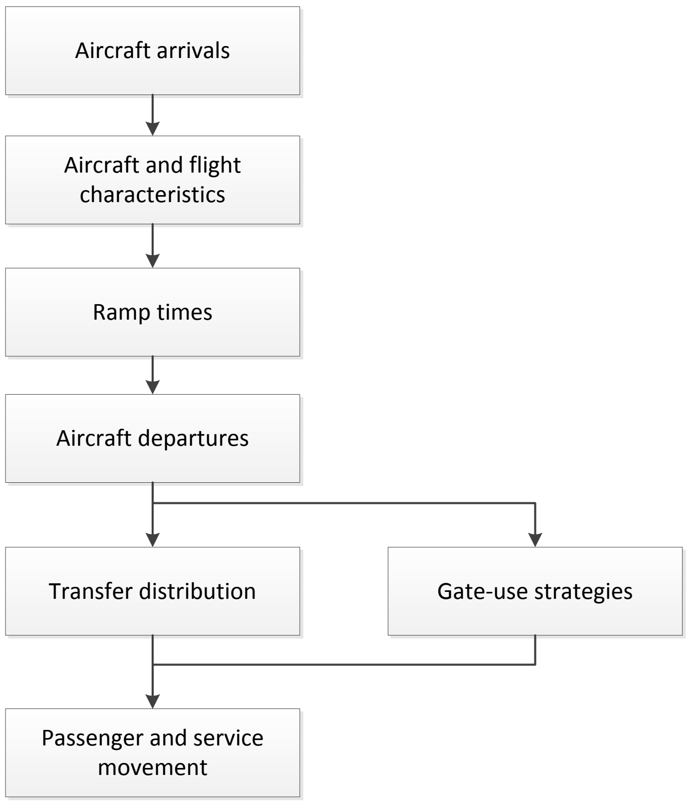


Figure 2. 3 Simulating ramp time in airport (Baron 1969)

The continuous increase in the demand of air traffic growth has pushed airports towards reaching their maximum capacity. For this reason, delays are increasing, and safety is becoming a more critical issue. Xie et al. (2004) have offered a simulation model with agent-based stochastic ruler to examine the associations between airport arrival capacity, delay, and safety. Their first step is revealing key ideas by simplifying a queue model. Their second move is calibrating to the chosen airport "Hartsfield Atlanta International" by describing an agent-based model. That is concluded by checking the trade-offs between the system capacity and safety, along with assessing numerous operational scenarios in this analysis.

Analysis of passenger flow in the airport terminal from entrance to boarding is found to be significant in delivering the capability study of best adaptable configurations. Discrete Event theory was used to carry out that type of study in Naples Airport Italy Capodichino (NAP) to estimate delays and to create logical and rational decisions by building a simulation model structure (Guizzi et al., 2009). The study brought visions to operational characteristics of a wide range of airport terminals, enabling a quick and easy modular building model.

2.9 Summary

To sum up, many studies have taken place on airport terminal performance evaluation: some used customers' perceived experiences in the terminal, others used simulations. In addition to these simulations, a holistic approach was used by considering the operations carried out in the terminal. The common way to address any kind of research is to verify the approach that is selected on one or more case studies. LOS is widely addressed from the 1970's until today; elements are added and others eliminated according to the context. The modelling has taken many forms in this field, although DEA and DES are widely used. Airport planning and performance evaluations are highly considered as an output from airport studies.

Chapter 3 Theory and Tools

3.1 Arena Software

Arena is a DES or discrete event simulation and computerization program created by Systems Modelling and procured by Rockwell Automation in 2000. It utilizes a SIMAN processor and simulation language. As of June 2012, it is Arena version 14 (the first version with online 3D visualization software). It has been inferred that Arena may join other Rockwell programming bundles under the "Factorytalk" brand (www.arenasimulation.com).

In the software environment, the client constructs a test model by setting modules (elements of distinctive shapes) that express methodologies or rationale. Connector lines are utilized to join these modules together and define the stream of substances. While modules have particular activities in respect to substances, stream, and timing, the exact representation of every module and substance with respect to genuine articles is down to the modeller. Measurable information, for example, process duration and WIP (work in procedure) levels, can be recorded and yielded as reports.

Arena could be incorporated with Microsoft innovations. It incorporates Visual Basic for Applications so models can be further automated if particular calculations are required. Likewise it can import from Microsoft Visio flowcharts, and can also communicate with Excel spreadsheets and Access databases for inputting or outputting data. Facilitating ActiveX controls is additionally included.

3.2 SPSS

Statistical Package for the Social Sciences or IBM SPSS Statistics is computer software used for statistical analysis of raw data. The software family can be used for collecting data by creating and deploying a survey, text analytics, data mining, and integration with other applications by batch and automated scoring services. This software is used mainly to analyse the collected data from the survey or data gathered from various simulation scenarios to identify any relationship between any two measured elements. The other purpose behind SPSS is defining that relation by regression. With SPSS software, that can predict what will occur next to allow making smarter decisions, solving mathimatical problems and improve results.

3.3 MATLAB

MATLAB stands for Matrix Laboratory and is a numerical processing and computing environment for handling engineering and scientific calculations. Matrix laboratory, as the name indicates, was created to ease matrix calculation. MATLAB is a high-level language and interactive environment for numerical calculation, modelling, visualization, and programming. Over a million scientists and engineers in industry and academia use MATLAB, the language of technical computing (mathworks.co.uk n.d.). The software is advanced by Mathworks. MATLAB is capable of analysing data, developing algorithms, creating models and applications, network controls, applying different algorithms like GA, plotting of data and functions, producing client interfaces, and interfacing with modules and projects composed in different computer applications like spreadsheets or traditional programming languages, such as C/C++ Fortran, or Java (Hahn and Valentine 2013).

3.4 Correlation

A dependence or reliance is any statistical association between arbitrary variables, which might not be related by a functional relationship (Encyclopaedia of Mathematics, n.d.). The survey carried out in this project explores the level of service in airport terminal management from the customer's viewpoint; it has many factors that can be varied from the opinion of each passenger that can be an input to a correlation. Secondly, the simulation model scenarios offer many random variables, which can fit this definition as this mathematical tool can identify that dependence and the significance level as will be shown below.

3.5 Bivariate Correlation

In SPSS the Bivariate Correlations method works out Pearson's association coefficient, Spearman's rho, and Kendall's tau-b with their significance levels. Correlations determine how variables or rank levels are connected. When ascertaining a relationship coefficient, it is necessary to screen the information for outliers (which can cause deluding) and proof of a linear association. Pearson's relationship coefficient is a measure of that linear connection. Two variables could be exceptionally related, yet the type of that relationship is not linear; in that case Pearson's association coefficient is not an appropriate method for measuring their relationship.

Example: does the number of games won by a team correspond with the normal number of focuses scored for every amusement? A scatterplot shows that there is a straight relationship. Investigating information from the 1994–1995 NBA season yields that Pearson's relationship coefficient (0.581) is critical at the 0.01 level see figure 3.1. You may suspect that the more games won for every season, the fewer focuses the opponents scored. These variables are contrarily corresponded (–0.401), and the relationship is huge at the 0.05 level (IBM.com, 2011).

Correlations

		locus of control	self-concept	motivation	reading score	writing score	math score	science score	female
locus of control	Pearson Correlation	1	.171	.245	.374	.359	.337	.325	.113
	Sig. (2-tailed)		.000	.000	.000	.000	.000	.000	.005
	N	600	600	600	600	600	600	600	600
self-concept	Pearson Correlation	.171	1	.289	.061	.019	.054	.070	-.126
	Sig. (2-tailed)	.000		.000	.138	.634	.190	.087	.002
	N	600	600	600	600	600	600	600	600
motivation	Pearson Correlation	.245	.289	1	.211	.254	.195	.116	.098
	Sig. (2-tailed)	.000	.000		.000	.000	.000	.005	.016
	N	600	600	600	600	600	600	600	600
reading score	Pearson Correlation	.374	.061	.211	1	.629	.679	.691	-.042
	Sig. (2-tailed)	.000	.138	.000		.000	.000	.000	.307
	N	600	600	600	600	600	600	600	600
writing score	Pearson Correlation	.359	.019	.254	.629	1	.633	.569	.244
	Sig. (2-tailed)	.000	.634	.000	.000		.000	.000	.000
	N	600	600	600	600	600	600	600	600
math score	Pearson Correlation	.337	.054	.195	.679	.633	1	.650	-.048
	Sig. (2-tailed)	.000	.190	.000	.000	.000		.000	.238
	N	600	600	600	600	600	600	600	600
science score	Pearson Correlation	.325	.070	.116	.691	.569	.650	1	-.138
	Sig. (2-tailed)	.000	.087	.005	.000	.000	.000		.001
	N	600	600	600	600	600	600	600	600
female	Pearson Correlation	.113	-.126	.098	-.042	.244	-.048	-.138	1
	Sig. (2-tailed)	.005	.002	.016	.307	.000	.238	.001	
	N	600	600	600	600	600	600	600	600

Figure 3.1 correlation using SPSS, which can identify correlation to certain significant level

3.6 Linear Regression

Linear regression is a method of predicting the value of a variable based on the value of another variable by representing the relationship between a scalar dependent variable ‘y’ and one or more explanatory variables indicated by ‘x’. The predicted variable is called the dependent variable. The variable used to predict the other variable's value is called the independent variable. When using one descriptive variable it is called “simple linear regression” (Weisberg, 2005). Simple linear regression involves two functions: the mean function and the variance function as expressed by:

$$
\begin{aligned}
\mathrm{E}(Y|X=x) &= \beta_0 + \beta_1 x \\
\mathrm{Var}(Y|X=x) &= \sigma^2
\end{aligned}
\tag{3.1}
$$

This was first presented and introduced in "Regression towards mediocrity" by British biologist Francis Galton (Galton 1886). The tool is only appropriate if the relationship between both variables is linear, otherwise the estimated results may deviate from the actual readings gathered (as illustrated in figure 3.2). A linear relationship can be checked after obtaining the values and using some inputs to produce a simulation model to compare with the linear regression.

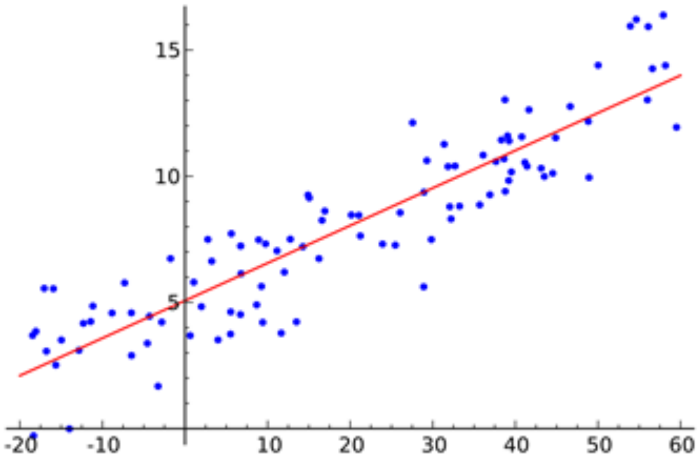


Figure 3.2 Linear regression x-y plot

Lewis-Beck (1993) considers regression analysis to be one of the most useful tools for researchers in quantitative analysis and understanding; it can also help to master other analysis methods. That can create a dependent y variable of contains a set of variables x_1 , x_2,..., x_i as illustrated in:

$$
\begin{gathered}
y = f(x_1, x_2, x_3, \ldots.) \\
y = b_0 + b_1 x_1 + b_2 x_2 + b_3 x_3 + \cdots
\end{gathered}
\tag{3.2}
$$

3.7 Levenberg-Marquardt

Levenberg-Marquardt is a widely held substitute to the Gauss-Newton technique of locating the minimum of a certain function $f(\mathbf{x})$ which is a summation of least squares of nonlinear functions. The Levenberg-Marquardt (LM) calculation is an iterative system that finds the lowest value of a multivariate function that is communicated as the total sum of squares of non-linear real-valued functions (Levenberg, 1944; Marquardt, 1963). It has turned into a standard solving mechanism for non-linear least-squares issues (Lawson and Hanson, 1974; Van Huffel and Vandewalle, 1991), broadly embraced in a wide range of controls. LM could be considered an integration of "steepest plunge" and the "Gauss-Newton" technique. At the point when the current result is a long way from the correct one, the calculation carries on like a "steepest drop" technique: gradual, yet guaranteed to meet. At the point when the current result is near the correct result, it turns into a Gauss-Newton method. After that, a short depiction of the LM calculation dependent upon the material in Madsen et al. (2004) is included. Note, in any case, that a detailed analysis of the LM calculation is further than the extent of this mentioned here and for a more comprehensive study it can be easily accessed in (Madsen et al., 2004; Nielsen, 1999; Nocedal and Wright, 1999; Kelley, 1999; Press et al, 1992; mathworks.co.uk, n.d.).

3.8 The Levenberg-Marquardt Algorithm

In the description below, vectors and arrays are shown in bold and $^{\boldsymbol{T}}$ is utilized to indicate transposition. Additionally, $\|.\|$ and $\|.\|_\infty$ indicate to the 2 and infinity norms. f represents a practical functional relation which maps a parameter vector $\mathbf{P} \in \mathcal{R}^m$ to an expected estimation measurement vector $\hat{\mathbf{x}} = f(\mathbf{P})$, $\hat{\mathbf{x}} \in \mathcal{R}^n$. The starting parameter estimate $\mathbf{P_0}$ and a measured vector $\mathbf{x}$ are given and it is needed to discover the vector $\mathbf{P}^+$ that best fulfils the functional relation f, that minimizes the squared distance $\epsilon^T\epsilon$ with $\epsilon = \mathbf{x} - \hat{\mathbf{x}}$. The principle of the LM calculation is a straight close estimation on a linear basis to f in the neighbourhood of $\mathbf{P}$. For a small $\|\delta_\mathbf{P}\|$, a Taylor series development prompts the estimate:

$$f(\mathbf{P} + \delta_\mathbf{P}) \approx f(\mathbf{P}) + \mathbf{J}\delta_\mathbf{P}, \tag{3.3}$$

Where $\mathbf{J}$ is the Jacobian matrix $\frac{df(\mathbf{P})}{d\mathbf{P}}$. LM is found to be iteratively similar to a non-linear optimisations routine: $\mathbf{P_0}$ is the Initiation stage, the approach creates a series of vectors $\mathbf{P_1}, \mathbf{P_2}, \ldots,$ that can converge up to nearby minimizer $\mathbf{P}^+$ for f. Thus, it is essential to discover the $\delta_\mathbf{P}$ that minimizes the value of $\|\mathbf{x} - f(\mathbf{P} + \delta_\mathbf{P})\| \approx \|\mathbf{x} - f(\mathbf{P})\| - \mathbf{J}\delta_\mathbf{P} \approx \|\epsilon - \mathbf{J}\delta_\mathbf{P}\|$, at each step. The found $\delta_\mathbf{P}$ is consequently the answer for a linear least squares problem: the base is achieved when $\mathbf{J}\delta_{\mathbf{P}} - \epsilon$ is orthogonal to the section space of $\mathbf{J}$. This prompts $\mathbf{J}^{T}(\mathbf{J}\delta_{\mathbf{P}} - \epsilon) = 0$, that yields $\delta_{\mathbf{P}}$ as the result of the assumed equations (Golub and Van Loan, 1996):

$$\mathbf{J}^{T}\,\mathbf{J}\delta_{\mathbf{P}} = \mathbf{J}^{T}\epsilon \tag{3.4}$$

Past $\mathbf{J}^{T}\,\mathbf{J}$ matrix in the left hand side of Eq. (3.4) is the approximate Hessian that means a matrix approximation to the second derivative order. The LM strategy illuminates a slight variant of Eq. (3.4), identified as the augmented normal equations

$$\mathbf{N}\delta_{\mathbf{P}} = \mathbf{J}^{T}\epsilon \tag{3.5}$$

Where the set of elements of a matrix that don not lie on a line joining two opposite corners or off-diagonal components of $\mathbf{N}$ are the same as $\mathbf{J}^{T}\,\mathbf{J}$ and the diagonal components are given by $\mathbf{N}_{ii} = \mu + [\mathbf{J}^{T}\,\mathbf{J}]_{ii}$ for $\mu > 0$. The procedure of changing the diagonal components of $\mathbf{J}^{T}\,\mathbf{J}$ is called damping and μ is found to be as the damping term. Assuming that the changed parameter vector $\mathbf{P} + \delta_{\mathbf{P}}$ while $\delta_{\mathbf{P}}$ gathered from Eq.(3.5) prompts a decrease in the error $\delta_{\mathbf{P}}$, the change is recognized and the procedure replicates with a reduced damping term. Overall, the damping term is expanded, the augmented normal equations are solved again and the procedure repeats until the amount of $\delta_{\mathbf{P}}$ that reduces the error is reached. The methodology includes applying Eq.(3.5) over and over for distinctive values of the damping term until a satisfactory change to the parameter vector is discovered to be related to one iteration of the LM calculation.

The damping term is balanced at every iteration to guarantee a decrease in ϵ. Matrix $\mathbf{N}$ in Eq. (3.5) is almost diagonal and the LM change step $\delta_{\mathbf{P}}$ is close to the steepest descent direction by assuming that the damping is set to a large value. Furthermore, the extent of $\delta_{\mathbf{P}}$ is decreased in that status. Damping likewise deals with cases where the Jacobian is rank deficient and $\mathbf{J}^{T}\,\mathbf{J}$ is singular (Lampton, 1997). In that strategy, LM can protectively explore an area of the parameter space in which the mathematical model is remarkably nonlinear. In the event that the damping is little, the LM step approximates the quadratic step properly for a completely linear problem. LM is used since it controls its own particular damping:

it increases the damping if a step neglects to decrease ϵ; other than that it decreases the damping. By that LM is fit to interchange between a slow descent approach when it is far from the minimum and a fast convergence when it is located in the minimum's neighbourhood (Lampton, 1997). The LM calculation ends when no less than one of the accompanying conditions is met:

- The size of the inclination of $\epsilon^{\boldsymbol{T}}\epsilon$, i.e. $\mathbf{J}^{\boldsymbol{T}}\epsilon$ in the right side of Eq. (3.4), decreases beneath a limit ε_1
- The relative update in the size of $\delta_{\mathbf{P}}$ falls beneath an edge ε_2
- The error $\epsilon^{\boldsymbol{T}}\epsilon$ decreases beneath an edge ε_3
- a number of cycles or iterations κ_{max}, is reached as maximum

Assuming that a covariance matrix $\sum_{\mathbf{x}}$ for the gathered vector $\mathbf{x}$ is available, it could be incorporated into the LM calculation by minimizing the squared $\sum_{\mathbf{x}}^{-1}$ norm $\epsilon^{\boldsymbol{T}}\sum_{\mathbf{x}}^{-1}\epsilon$ rather than the Euclidean $\epsilon^{\boldsymbol{T}}\epsilon$. Likewise, the minimum value is obtained by solving a weighted least squares problem characterized by the weighted normal equation

$$\mathbf{J}^{\boldsymbol{T}}\textstyle\sum_{\mathbf{x}}^{-1}\mathbf{J}\delta_{\mathbf{P}} = \mathbf{J}^{\boldsymbol{T}}\textstyle\sum_{\mathbf{x}}^{-1}\epsilon \tag{3.6}$$

Whatever is left of the calculation remains unaltered. The complete LM calculation is demonstrated in a pseudo code in Figure 3.3. It is inferred by minor adjustment of the calculation by Madsen et al. (2004, p29); more insights in regards to the LM calculation might be perceived there. Characteristic values for the client characterized parameters are $\boldsymbol{T} = 10^{-3}$, $\varepsilon_1 = \varepsilon_2 = \varepsilon_3 = 10^{-15}$, $\kappa_{max} = 100$. Levmar is C/C ++ application of this Levenberg-Marquardt algorithm that can be freely accessed at (ics.forth.gr, 2005).

Input: A vector function $f : \mathcal{R}^m \rightarrow \mathcal{R}^n$ with $n \geq m$, a measurement vector $\mathbf{x} \in \mathcal{R}^n$ and an initial parameters estimate $\mathbf{p}_0 \in \mathcal{R}^m$.
Output: A vector $\mathbf{p}^+ \in \mathcal{R}^m$ minimizing $||\mathbf{x} - f(\mathbf{p})||^2$.
Algorithm:
$k := 0; \nu := 2; \mathbf{p} := \mathbf{p}_0;$
$\mathbf{A} := \mathbf{J}^T\mathbf{J}; \epsilon_\mathbf{p} := \mathbf{x} - f(\mathbf{p}); \mathbf{g} := \mathbf{J}^T\epsilon_\mathbf{p};$
stop:=($||\mathbf{g}||_\infty \leq \varepsilon_1$); $\mu := \tau * \max_{i=1,...,m}(A_{ii});$
while (not stop) and ($k < k_{max}$)
  $k := k + 1;$
  repeat
    Solve $(\mathbf{A} + \mu\mathbf{I})\delta_\mathbf{p} = \mathbf{g};$
    if ($||\delta_\mathbf{p}|| \leq \varepsilon_2||\mathbf{p}||$)
      stop:=true;
    else
      $\mathbf{p}_{new} := \mathbf{p} + \delta_\mathbf{p};$
      $\rho := (||\epsilon_\mathbf{p}||^2 - ||\mathbf{x} - f(\mathbf{p}_{new})||^2)/(\delta_\mathbf{p}^T(\mu\delta_\mathbf{p} + \mathbf{g}));$
      if $\rho > 0$
        $\mathbf{p} = \mathbf{p}_{new};$
        $\mathbf{A} := \mathbf{J}^T\mathbf{J}; \epsilon_\mathbf{p} := \mathbf{x} - f(\mathbf{p}); \mathbf{g} := \mathbf{J}^T\epsilon_\mathbf{p};$
        stop:=($||\mathbf{g}||_\infty \leq \varepsilon_1$) or ($||\epsilon_\mathbf{p}||^2 \leq \varepsilon_3$);
        $\mu := \mu * \max(\frac{1}{3}, 1 - (2\rho - 1)^3); \nu := 2;$
      else
        $\mu := \mu * \nu; \nu := 2 * \nu;$
      endif
    endif
  until ($\rho > 0$) or (stop)
endwhile
$\mathbf{p}^+ := \mathbf{p};$

Figure 3.3 Levenberg-Marquardt Algorithm

3.9 Neuro-Fuzzy Model

Fuzzy inference system simply descried as inputs entered fuzzification interface that entered to decision-making unit which enters to defuzzification interface that generates output under influence of the knowledge base that effected both fuzzification and defuzzification interface (see figure 3.4).

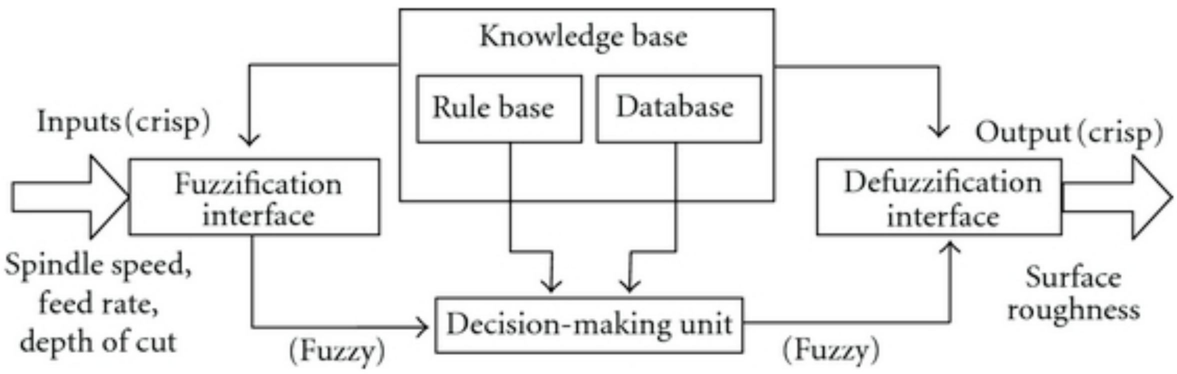


Figure 3.4 Fuzzy inference system (Jang, 1993)

In the computing field, Neuro-Fuzzy (NF) is known as an integration of neural networks and fuzzy logic (Jang, 1993). Self-learning is an element that is used by processing data samples to save its fuzzy sets and fuzzy rules. A NF system is defined as a fuzzy system which employs a self-learning algorithm derived and inspired by neural network concepts to achieve its fuzzy sets and fuzzy rules using processing data samples (Al-Kanhal, 2010). In this research, simulation scenarios' results data (gathered from arena) is used to develop the NF system that models the airport performance factors such as the number of disposed passengers and total passenger time.

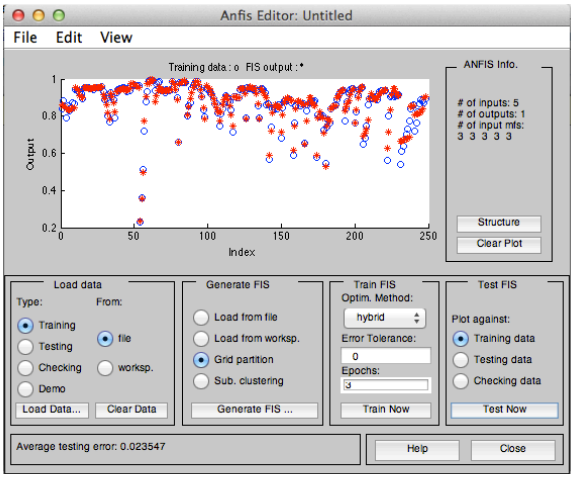


Figure 3.5 Anfis Editor in Matlab

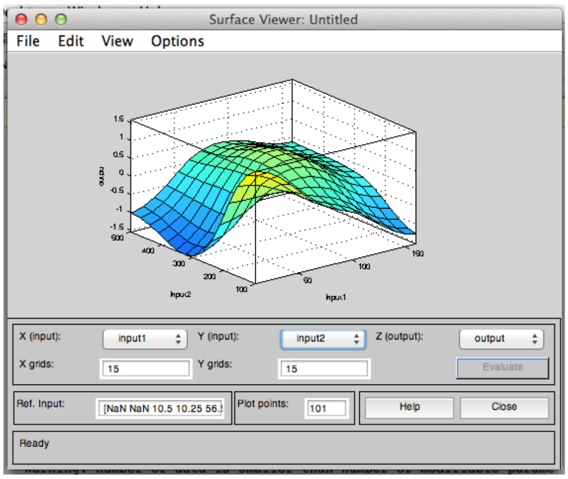


Figure 3.6 Matlab Surface Viewer

Fuzzy inference frameworks have been adequately useful in various deductive and designing issues throughout recent years. The gain of tackling complex nonlinear issues by using fuzzy rationale techniques is that the experience or master's information portrayed as the Fuzzy standard base could be straightforwardly implanted into the framework for controlling and managing the issues as it is illustrated in figure 3.7 (Chen et al., 2007; Takagi and Sugeno, 1985; Xu and Lu1,1987; Ying, 2000).

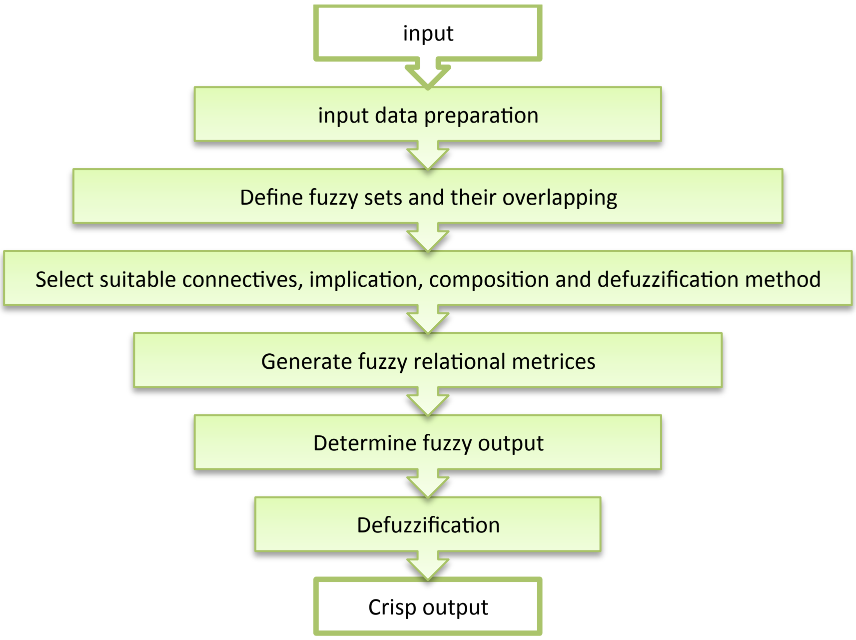


Figure 3.7 Flowchart for the development of a fuzzy logic simulator (Chaturvedi, 2010)

The Adaptive-Network-based Fuzzy Inference System (ANFIS) contains fuzzy models under the framework of adaptive networks which have certain benefits over neural systems (Jang, 1995) as it is illustrated in figure 3.5 and 3.6.

3.10 Optimisation

Optimisation could be characterized as an arrangement of movements pointed at the most conceivable answers for any given problem. The easiest case of optimisation is the minimisation or maximisation of real functions by picking the substitutive values of real or integer number variables from inside a conceivable set. Consequently, optimisation procedures are characterized in the first case on many objective functions to be accomplished, from being either a Single Objective Function or Multi Objective Function. Moreover, they can likewise be arranged into two fundamental classes being either a Deterministic Algorithm where all the variables are deterministic, or a Probabilistic or Stochastic Algorithm where some or all of the parameters are probabilistic.

Grouping dependent upon the presence of constraints could be conducted when constrained optimisation issues are liable to one or more constraints, while unconstrained optimisation issues are those without any constraints. Taking assembling procedure optimisation methods as an illustration, these could be split into two classes (Saravanan, 2006). The usual optimisation procedures utilise immediate hunt and the angle look routines while smart optimisation systems utilize methods, for example, using genetic algorithms, simulated annealing, particle swarm optimisation, ant colony and tabu search. Recently, wise optimisation procedures have been connected effectively to comprehend diversity of complex optimisation issues.

In this research, two streamlining approaches will be used: Genetic Algorithm (GA) (Goldberg, 1989) and Particle Swarm Optimisation (PSO) (Kennedy and Eberhart, 1995). Their algorithms are briefly described in this chapter.

3.10.1 Genetic Algorithm Concept

Genetic Algorithm was invented by John Holland in 1965 (Holland, 1975), when he was studying the phenomenon of adaptation as it happens in nature and simulating the principle of natural genetics to solve specific problems (Mitchell 1998). It was used for determining the optimal solutions for an optimisation accomplished by investigative search and optimisation method applied in computing. This algorithm has been broadly applied to solve many engineering optimisation problems.

The explanation behind GA's extensive acknowledgement and application is its advantages over other approaches, some of which are:

- It does not require numerous prerequisites to execute, for example, derivative information or auxiliary knowledge
- The GA uses probabilistic transition rules as opposed to deterministic ones.
- The algorithm calculation works successfully as a global optimizer.
- During the search population focuses might be carried out in parallel rather than on a single point which can provide many possibilities simultaneously in efficient way.

3.10.2 Genetic Algorithms Description

Genetic Algorithms is an investigative inquiry and optimization technique that was developed in the field of biological natural development and genetics (Holland, 1975). As noticed, GA is a metaheuristic methodology which does not need numerical interpretations of the optimisation issue, however GA depends on an expense capacity or the cost function, so as to survey the wellness or fitness of a specific answer for the issue being referred to. Algorithms of that kind give strong and effective finding in the population space. Figure 3.8 illustrates the flowchart of the fundamental Genetic Algorithm's operations.

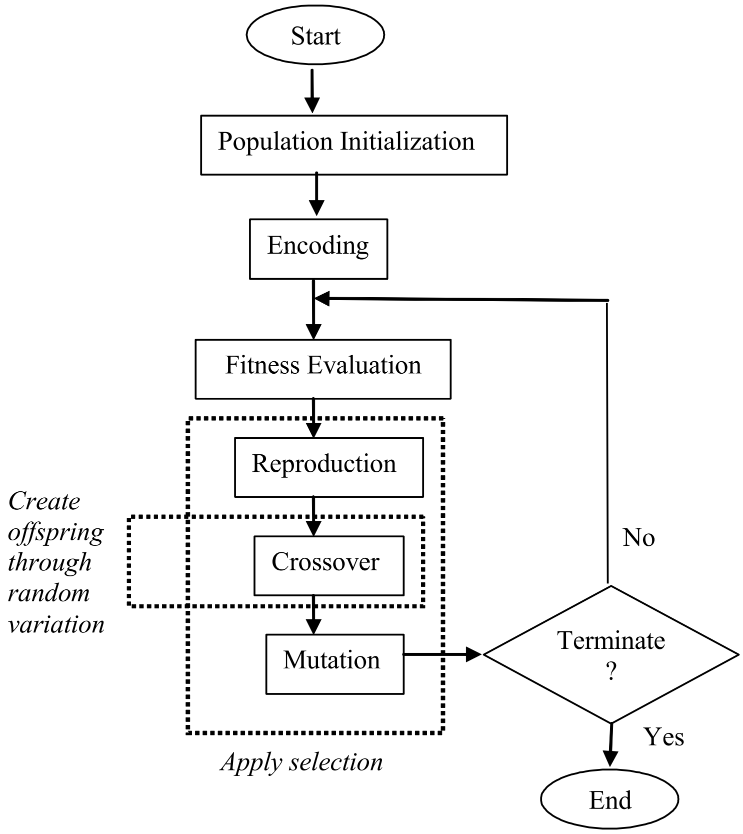
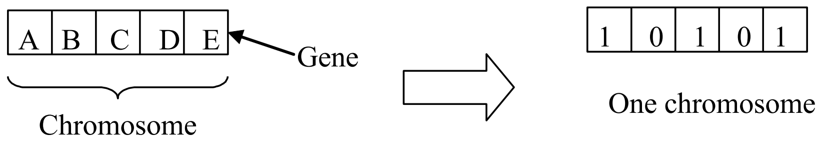


Figure 3.8 Genetic Algorithms flowchart

As indicated in Figure 3.8 the GA will begin by:

First, initial population: possible result particles are pronounced by creating some individuals that make the first population of chromosomes as they are created arbitrarily where each one forms an alternate answer for the issue. The number of chromosomes controls the population in each generation.

Second, encoding: the issue is encoded into chromosomes that are placed in a set of strings, that leads every individual in population to be encrypted as a binary string holding an overall characterized number of bits (1's and 0's). A chromosome illustration is indicated in Figure 3.9 (a), where a chromosome is a show of qualities. Each gene has to change over to either 0 or 1, as demonstrated Figure 3.9 (b).



(a) Normal chromosome (b) GA chromosome

Figure 3.9 Chromosome

Third, Evaluation: each individual in the population is evaluated using the cost function. Each string expresses an answer and is allocated a wellness quality to decide the fitness of each string . The greater the value of fitness in the cost function of a string, the greater the probability of survival.

Fourth, reproduction: in this process best iterations are picked by positioning them as indicated in Figure 3.10 as per the past process, Evaluation process. This operation models the common "survival of the fittest" system. Fitter results survive and are duplicated into cutting edge while frail ones die.

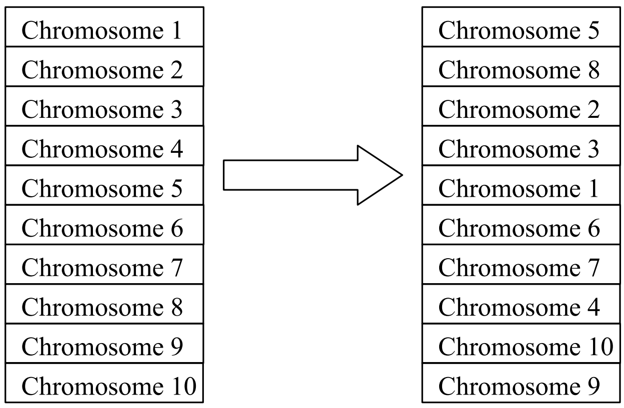


Figure 3.10 GA Reproduction

Fifth, crossover so as to make an alternate better group of individuals than the starting one. A mating methodology is completed among the fittest population in ascendance, since the relative wellness of every individual is utilized as a standard for decision. Subsequently, the chosen individuals are arbitrarily consolidated in sets of two off-springs by traverse parts of their chromosomes at a haphazardly picked position of the string. These pairs of off-springs should form a finer answer for the issue (Smith, 2002). Parent pair strings are cut at the same point and generations to come are generated by joining together corresponding qualities from them in a one-point crossover. On the other hand parents are cut at two places and later generations are shaped by embedding the inside string from the first parent into the other parent and the other way around in a two-point crossover. Different sorts of crossover are available, for example, uniform, in which later generations are created by taking a specific number of parent genes from each one, with no exception on where these genes are located in the string set (see Figure 3.11).

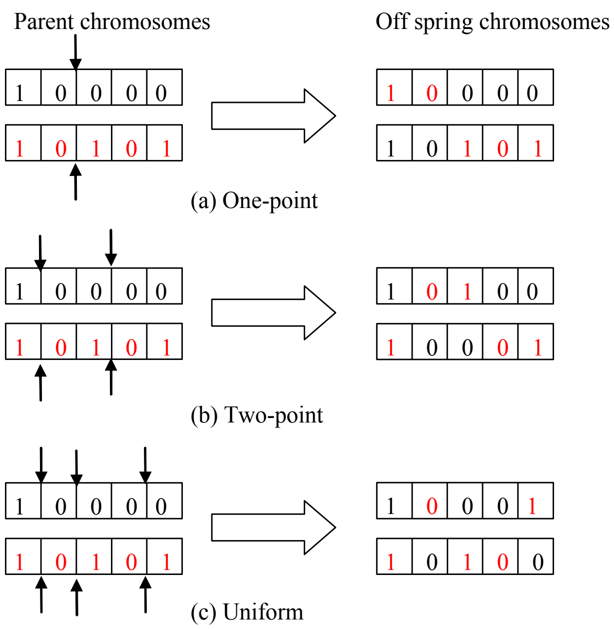


Figure 3.11 Genetic Algorithms crossover types:
(a) One-point, (b) Two-point, and (c) Uniform

Sixth, Mutation: so as to give some variation to the procedure of creating individuals, arbitrarily picked strings bits are modified or triggered (as 0's changed to 1's and 1's to 0's). This process is identified as mutation and serves to accelerate joining and keeps away the population from being controlled by a minority.

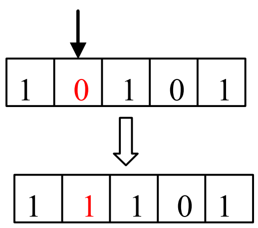


Figure 3.12 GA mutation

This procedure is done several times while waiting for an end condition to be fulfilled. Basic ending conditions are (Kent and Williams, 1998):

1. A result is discovered that fulfils least criteria,
2. generation assigned number reached
3. Assigned cost plan reached for instance budgeted money or allocated time for computing.
4. The most fitness positioning results reached at a level such that in progressive results no more improvement can be achieved.
5. Manual examination.
6. Mixtures of ending conditions already mentioned.

By considering all of that, it guarantees that the result set is never unfilled. Nevertheless, it ought to be arrived at without too much or too little randomness by picking some level of mutation. The effective capability of GA improvement has meant that the strategy has been used for many optimisation purposes (Coverley and Staszewski, 2003; Kobayashi and Simon, 2005; Xu et al. 2010; Ohira et al., 2005).

3.10.3 The Concepts of Particle Swarm Optimisation

Particle Swarm Optimisation or PSO is a computational technique for stochastic optimisation by iteratively trying to improve a candidate solution and it relies on the movement and intelligence of the swarm to improve a candidate solution by certain quality measure. Bird flocking or fish schooling inspired the PSO concept as each individual in that swarm, called particles, moves around the solution area of the problem, searching for the best global solution among the best local solutions. As birds swarm search for food, each particle or bird looks randomly for a piece of food; they know how far away each bird or iteration is, but they do not know where is the food (global best solution). Once a particle or swarm member is nearest to the food it leads others to it (Al-Kanhal, 2010).

3.10.4 PSO Algorithm

Particle Swarm Optimization (PSO) (Kennedy and Eberhart, 1995) is a technique used for global optimization. PSO discovers the best answer for the issue that is treated as a point. Every particle is allocated a value according to the particle's position, in assessment of specific measurements. The best positioned particle observed conveys this position to other particles in the swarm. The swarm particles modify their own particular positions focused around that position. The correspondence might be basic to the entire swarm, or be partitioned into locals which have their own ‘bests’. Each known type of the PSO has particular and general features and qualities (Kennedy, 2006): First and foremost, every type or version utilizes a population of particles.

Secondly, every swarm has mathematical properties or topology representing the particle association within the particles. The traditional one, getting to be to some degree out of date yet broadly utilized, uses gbest and pbest. The gbest topology could be understood by observing a completely organized and associated population; that may be, each individual might be impacted by every other one. Typically, this implies that particles in PSO are influenced by the particle that has discovered the best issue result as such (the absolute best one among individuals). In this way however, gbest holds the best conceivable number of associations between sets of particles, in execution it truly just means continuing to notice the best result observed. The pbest topology is a loop cross section, where each individual is associated with the members of each set in the population. The benefit of this arrangement is that subpopulations can unite on differing optima in the search space independently. Subsequently the pbest topology, however regularly slower to merge on an ideal, is additionally less vulnerable to the charm of nearby optima; its hunt is slower and more exhaustive than gbest's.

Third, the standard for each individual is some decision of a change principle. The individual travels from side to side hunting in the population space, choosing a point at time t that is reliant on its location at t-1, its last found best, and the past accomplishments of its neighbour. There is a standard equation for deciding the following checking point, however this has developed, and random number generators have been used by some analysts by deviating the search area from time to time avoiding trap in certain space of solutions to allow more accurate global best particle finding.

Fourth, the normal for all recognized PSO is the thing that may approximately be considered the interaction rule. Individuals treat their bests, and some other individuals’ bests, as a benchmark that affects the next particle to be checked in the searching space. The way this particle position point is picked, may take after some of various conceivable conditions and the rundown of principles is developing as specialists push the boundaries in this new searching area.

Considering the former criteria in execution, Clerc and Kennedy (2002) demonstrated the basic assertive type of the PSO, as indicated in Figure 3.13 and Figure 3.14, where particles are appointed with random generated positions x(t) and speeds v(t) and a wellness capacity is assessed, utilizing the PSO.

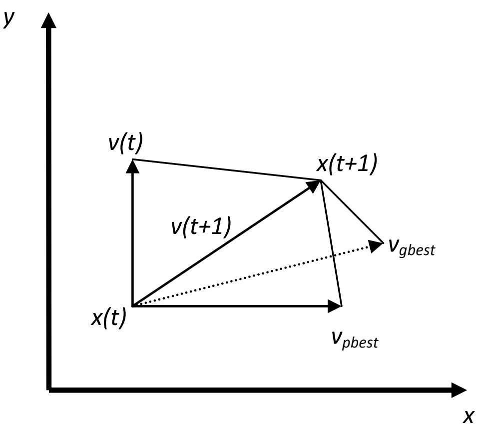


Figure 3.13 Concept of modification of a searching point by PSO

A function equation can affect positions and velocities that examine new particles with respect to the following two equations individually:

$$v(t+1) = wv(t) + \varphi_1 r_1 (pbest(t) - x(t)) + \varphi_2 r_2 (gbest(t) - x(t)) \tag{3.7}$$

and

$$x(t+1) = x(t) + v(t+1) \tag{3.8}$$

At the point when a particle finds sort of pattern that is superior to any it has discovered before, it saves the directions to pbest(t). The dissimilarity between pbest (the best point observed until this moment) and the present position is randomly combined to the present velocity, creating the route to waver nearby that point. In addition to that, every particle is characterized inside a boundary of a region containing the same point and some different particles. The random weighted subtraction between the global best position gbest(t) and the present position is additionally added to the velocity, altering it for the following step. These changes to the particle's position development within the space leads it to find nearby the two best points as demonstrated in equation Eq (3.7).

where w is the weight called inertia weight, that is substituted as a constant value or associated with time linearly, φ1 and φ2 are arbitrary positive unchanged constants named "cognitive" and "social" parameters, both represent the impact of the two diverse swarm memories, and r1 and r2 are randomly generated numbers between 0 to 1. Once the velocity has been figured, the positions are calculated by the relation Eq (3.8).

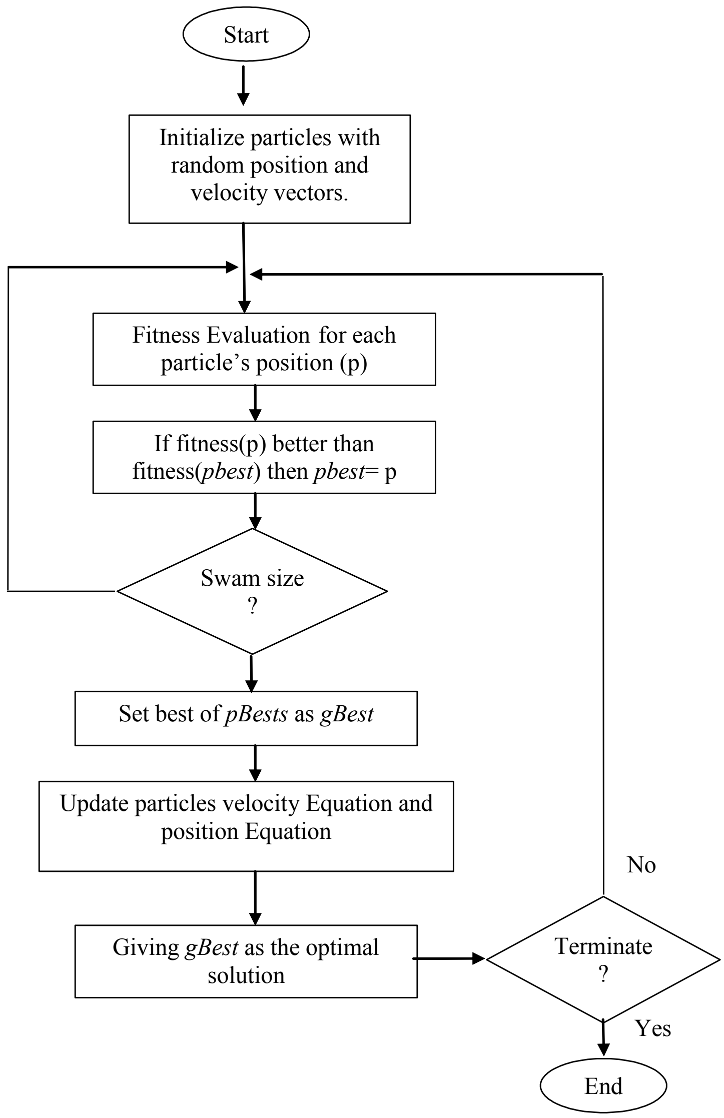


Figure 3.14 Typical flowchart for Particle swarm optimization

GA and PSO both have level of similarity and some differences as revealed earlier in this chapter these are briefly summarised in the following table 3.1.

Table 3.1 GA and PSO comparison

	GA	PSO
1.	Based on survival of the fittest	All its particles are kept as members of the population through the course of the run. All particles remain and are considered as population members during execution.
2.	selection process is considered	no selection process considered
3.	uses crossover algorithm	The change to the best p(t) and g(t) is theoretically like the crossover process.
4.	mutation algorithm is used	Steadiness is attained over the inertial weight (w)

3.11 Summary

This chapter has revealed the most used elements in this research. All of them began with the tools used during data collection analysis out of arena simulation model report. Regression and correlation as techniques are missioned as that can be handled by SPSS for such gathered figures. LM is an alternative if a high error level is briefly described, while ANFIS can be more accurate. Arena can be used to generate stochastic ‘what if’ scenarios that facilitate studying deferent operation situations and strategies that relate to the airport terminal authority. That all together can allow input to be fed into described optimisers (GA or PSO) to show the decision making tool upon the cost function generated.

Chapter 4 Airport Survey

4.1 Survey Introduction

In the last few decades, the advancement of airport passenger terminals' administration-related measures have been one of the significant issues for airport operators, in the development of level of service (LOS) in particular. This has persuaded various LOS improvements via air transportation offices, together with FAA or the Federal Aviation Administration (Lemer, 1988; Airports Council International, 2000; Correia et al., 2008a; Correia et al., 2008b).

Regardless of the pressure on these operators or organizations, the proposed LOS benchmarks and techniques have been the subject of assessment by experts. One of the fundamental issues is the absence of traveller data or "lack of passenger input". A few studies have likewise been embraced to create routines for LOS assessment considering clients' observations or passengers' views. A large portion of them have presented outcomes dependent upon poor input data, and were not fit to be given a high level of importance for checking and criticizing the hypotheses considered.

Furthermore, most research work kept tabs on distinct elements of the airport traveller terminal (BHS, check-in counter, flight lounge, etc.), ignoring the 'in general' assessment. A wide measure reflecting the terminal overall (e.g., LOS) for a given sort of traveller (e.g., arriving) might be helpful in setting up, operating, configuring and administrating levels. With this kind of measure, it might be feasible to recognize the level of significance credited to distinct elements by travellers, and to prioritize some development needs over others.

Moreover, it might give a measure to examine different airport terminals with the end goal of evaluating their efficiency. The key challenge when creating an 'in general' measure is the data gathering. It is generally easy to gather attributes of distinct resources (e.g., the queuing time at the passport check counter) instead of getting in general measures (e.g., total waiting time in the airport by each passenger). A few issues must be tackled before an examination attempt is created to gather overall measures. It is the motivation behind this study to give a technique to such an attempt, representing it with an investigation of the King Abdul-Aziz international airport that will be modelled later upon the output of this survey.

A comprehensive review and evaluation of past studies on LOS has been introduced in Correia and Wirasinghe (2004). Mumayiz and Ashford (1986) proposed a perception–response idea, utilizing graphical presentations developed from traveller reactions regarding the LOS gathered from some airports in the UK. Omer and Khan (1988) engaged the idea of a utility hypothesis to create a relationship between characteristics of resources and facilities like waiting time or space available and client reactions (0 or 1) about the LOS presented. A psychometric scaling procedure was conducted by Müller and Gosling (1991) to acquire a quantitative measure of LOS that could be employed within a relationship like the one created by Omer and Khan (1988).

Seneviratne and Martel (1991) created LOS principles for a few elements of the runway traveller terminal. The determination of the most significant parts and measures was dependent upon a study of Canadian runways (Martel and Seneviratne, 1999). Ndoh and Ashford (1993) utilized hypotheses of observation and scaling to assess LOS on runway access, utilizing 12 characteristics like cost, comfort, access to information and so on.

Park (1994) employed fuzzy logic to determine LOS measures for particular elements of the airport terminal. The approach was connected to the Seoul Kimpo Airport. Yen (1995) conducted a review of Austin Municipal Airport in Texas, USA. He connected paired "logic" models to gauge a "long" model and a "short" model. The approach anticipates the probabilities that a traveller rates service on the basis of identified time measures. Yen et al. (2001) displayed a quantitative model to characterize the level of service at airport terminals. The model utilized fuzzy logic to associate subjective service rankings to time estimations of related waiting or service procedures.

Fernandes and Pacheco (2002) used data envelopment assessment to assess the capacity of some Brazilian airports, taking into account a few operational parameters e.g., number of check-in counters, normal space accessible for every traveller, and so on. Magri and Alves (2003) assessed the LOS presented by a number of Brazilian airports as a capacity of 36 subjective parameters proposed by the Airports Council International (ACI) (Airports Council International, 2000).

4.2 Facilities and characteristics of the airport terminal

The terminal area is the main crossing point connecting the runway and the rest of the airport. It is divided into three areas based on its functionality as has been described by Horonjeff et al. (2010) and activities which can be listed as:

- The access area – where the traveller exchanges from the access mode to the traveller handling and processing area. Parking, loading and unloading of travellers are done within this functional area.
- Processing – where the traveller is handled in the beginning, end, or in-between of his transportation journey. The essential exercises in this area are ticketing, check-in, luggage collection, seat arrangement and allocation, security check, administration and security.
- The flight edge – where the traveller exchanges from the processing region to the airplane. The exercises that happen here incorporate gathering, movement to and from the airplane, and boarding and unloading passengers.

To give an overall LOS assessment, it is important to point out the kind of movement being referred to. Travellers might be separated into three sets as stated by their movement nature: arriving, departing, and transfers. Every one of these sets will have a dissimilar collection of necessities and requirements and, as a rule, will even make utilization of certain resources. For example, travellers in departing mode will not make utilization of the baggage claim resources, and arriving travellers will not utilize the check-in area.

Subsequently, every movement type will have a LOS record which as an overall index includes the traveller's full terminal experience rather than simply evaluating one resource office or facility. In this survey, just-arriving international passengers are studied; nonetheless, the strategy displayed in this survey can likewise be connected to assess the LOS for departing (de Barros et al., 2007). Also, this examination focuses on operational parts of the terminal: therefore, any different segments situated outside of the terminal building are not dealt with.

Correia and Wirasinghe (2004) and Correia et al. (2008a; 2008b) considered the below listed factors in extracting the performance measures that evaluate the airport terminal:

- Curbside.
- Immigration and passport check.
- Baggage claim.
- Security checking area.
- Arrival lounge.
- Circulation regions (hallways, stairs, lifts, and so forth.).

Lastly, this survey introduces a generally LOS assessment as a capacity and functionality of the listed elements which inspired the prepared study:

1. Processing time experienced in the airport terminal: Total processing time required for passport control unit processing, customs inspection, luggage claiming and any other resources in the airport.
2. Delay in the airport terminal: Service times: check-in, baggage claim, waiting times, variability of wait, etc.
3. Comfort Cleanliness in the airport terminal: This concerns lighting and congestion level of waiting areas/lounges, and ambience of the airport as a whole.
4. Courtesy of staff in the airport terminal: Helpfulness, support and courtesy of the terminal employees. Accessibility and facilities for the disabled.
5. Convenience in the airport terminal: Availability/accessibility of trolleys, washrooms, shops, restaurants, money exchange, cash machines, luggage carts, and rental facilities trolleys.
6. Information visibility: Clearness and/or frequency of information display for flights, airport facilities and signposting. Flight information display system (FIDS).
7. Security: Satisfaction and feeling secured about security facilities and airport safety factors.
8. Service: Service "justice" (first in, first out), spatial logic, signing or sightlines reasonableness.

Four LOS measures are incorporated in the examination, as they have been distinguished as extremely significant for travellers (Corrie et al., 2005): “walking distance, total time, orientation and security environment”. The security environment factor varies essentially from security screening. Security environment depends on the clients' recognitions of security all around the terminal facilities. This is a subjective variable, which may impact on the in general LOS to a certain degree. Then again, security screening depends on the nature of the experience of the traveller when being checked at the security x-ray screening area.

Although some elements do not seem to be directly handled by the airport management company or the operator, they could have significant influence throughout the design and management phases. As an example, check-in counters are sometimes managed by airlines however they are typically planned and designed by the operators themselves. Moreover, in several countries the operator is answerable for allocating check-in areas consistent with demand priorities. The following are short details of the elements and measures that are studied.

4.3 Enplaning curb side

The curb side component is the crossing point between the terminal building and the ground transportation framework. High activity volumes and peaks, in addition to the complex streams of blending individuals and vehicles, may bring about far-reaching movement congestion at the curb side region. This may thus cause annoyance, disappointment, and suspension to travellers in large airports. Arbitrary standard requirements in various airports may prompt oversized or undersized offices. The airport group is, for that reason, intrigued by an approach that could prompt rational standards (Sodium, 1994).

4.4 Passport control process and immigration

The immigration department is responsible for passport control in airport terminals by permitting entry to the country. This will need to include checking and verifying passports, work permits, landing cards, Visit/Hajj/Umrah visas by using four databases (as listed by Shanks et al., 2004): the biometric/passport database, airport security database, police database, and immigration database. Shanks et al. (2004) concluded that databases should be integrated to attain better performance.

4.5 Baggage Handling System

The airport operator or the airport authority does the baggage handling administration for the carriers. Baggage Handling System (BHS) is progressively robotized and automated by utilizing the barcode tags to distinguish and control the luggage by computer system, and failures can originate from the mechanical conveyor and electric supply. For instance, Heathrow Airport has a framework with a cost of £42 million. This was introduced between 1995 and 1998 by BAA with a length of 1.4 km that started from terminal 1 to terminal 4. The conveyer generally has a width of 0.9 m and such a framework can distinguish items by carrier, flight no, and traveller. Additionally, the baggage make-up region is a crucial area for the departure and arrival process (Edwards, 2004). Edwards gave more details about the baggage system.

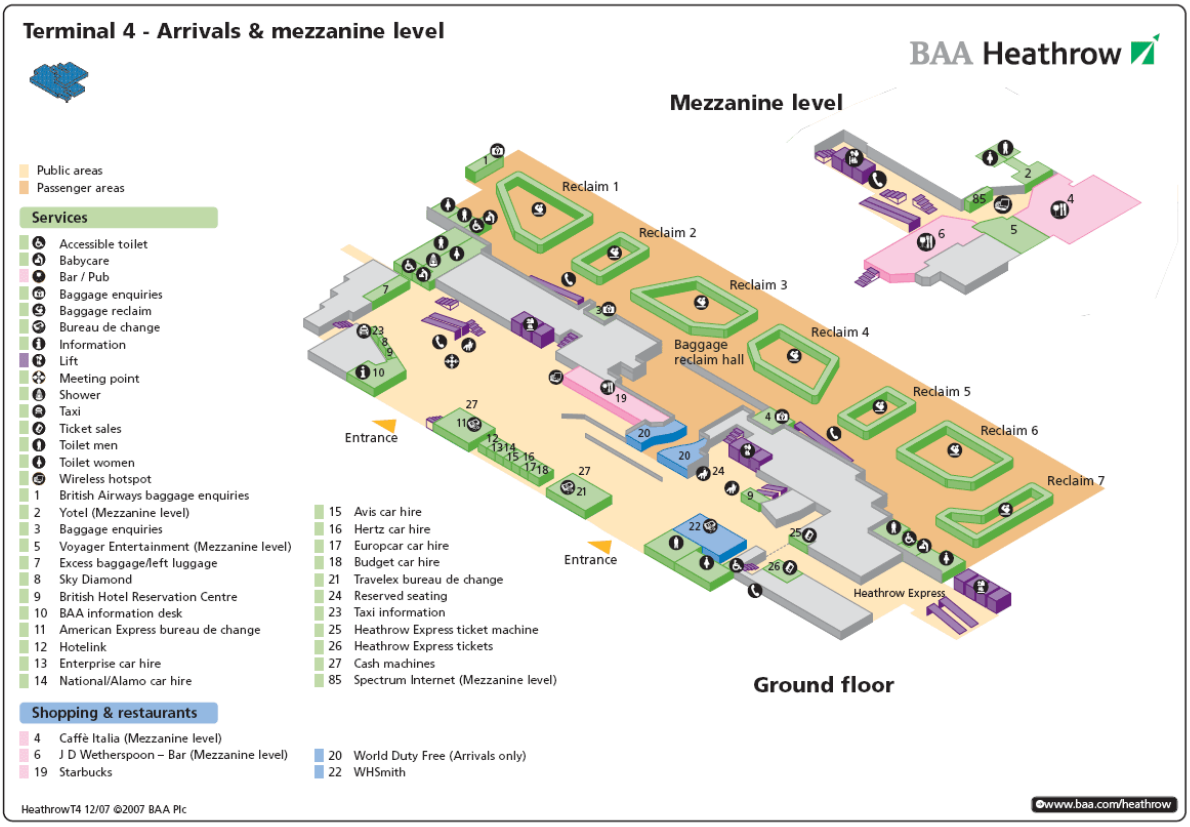


Figure 4.1 Baggage Handling System in terminal 4 of Heathrow Airport (Edwards, 2004) (baa.com, 2007) (aviationexplorer.com, 2007)

4.6 The Hajj Complex at King Abdul-Aziz Airport

This piece of architecture was designed by Skidmore Owings and Merrill in 1985. The terminal is known to be occupied during Hajj time or the pilgrimage period of the last month in the Islamic Hijri lunar year. The flights are scheduled a month before the Hajj starting date; only arrival flights form the traffic during that period. Then after Hajj performing time the departure mode is set up in the terminal. All scheduled flights are departing from the terminal. Six to eight weeks is the Hajj season terminal occupation. The passenger flow is naturally lit and a ventilated open-air structure. Recently, in 2007 PPMDC company was formed in partnership with Aéroports de Paris and was granted a 20 years' BTO contract with the Saudi Government. BTO stands for Build Transfer Operate as part of the Saudi privatization preparation to ensure a better service and launch a new benchmark of customer orientation in that particular area. They air-conditioned and developed the structure by dividing the terminal into modules to allow a better level of management (see figure 4.2).

Figure 4.2 The PPMDC offered a development design based on visual contact and guidance for passengers (through diverse colours).

The terminal is divided into five modules with a different colour for each module from the aircraft PBBs (Passengers Boarding Bridges) up to the passenger bus pick up area outside the terminal; these are distinguished easily by passengers for easy reference and guidance.

Figure 4.3 Ground floor of the Hajj terminal shows the five different modules.

Therefore, the Hajj Terminal is dedicated to be an international entry for pilgrims worldwide. Lately, it has been utilized for Umrah ('short pilgrimage' or 'lesser pilgrimage') seasons.

The design makes reference to the tented structures inspired by the culture and the history of the region. The terminal can handle up to 80,000 passengers at any time with a total area of 190,000 square meters. In 1990, the terminal gained an Aga Khan Award for building design for the way it satisfied the needs of international air transportation with a spiritual aspect.

4.7 Baggage claim

The baggage claim area (or baggage reclaim) in airport terminals is an area where arriving travellers claim checked-in baggage after landing from their airline flight. Commonly, the baggage claim area consists of conveyor systems or baggage carousels. To report missing baggage or to claim oversized baggage, the baggage claim area usually includes an airline's customer service desk. The baggage claim area is an area which comes after the immigration and passport check counters in international airports. Where conveyers are allocated and assigned for each flight depends on how far it is from the gate for the arrival flight in large airport terminals like this case. The Hajj terminal has the advantage of ten baggage conveyor belts with usability for both departure and arrival baggage with adding portable check-in counters. The baggage claim system can be either a single-level system or a multi-level system. In the former the items are delivered from a door or a hole in the wall while the latter has a feeder from either above or below the existing floor (see figure 4.4).

Figure 4.4 single-level system (left) and multi-level system (right).

4.8 X-ray Security screening

The main purpose of this area is detecting and preventing explosive or illegal items from entering the country in the arrival mode of the passenger process flow. Weapons, drugs and money are examples of unauthorized items.

The reason for screening of travellers before departure is to detect and prevent the carrying of items which could be harmful as a weapon or generally represent a danger to flight security. To accomplish that objective, it is important to examine the travellers, their portable items and baggage, in a way that is not too intrusive as that could reasonably be found to bring a large amount of anxiety and distress to the traveller. Moreover, the screening procedure must be quick and efficient so as to keep it away from a bottleneck in the traveller stream.

Security lanes are the typical models for traveller security checkpoints in most international airports. Each one of the security lanes contains an X-ray scanner. Travellers are asked to go through the magnetometer, which alerts if a metal item is discovered. The traveller's lightweight things –, for example, satchels, smart phones, small packs – are examined by the X-ray. The channels are installed at entries to the areas of access to the boarding gates, making a "protected" zone where all boarding gates are available and reachable just to individuals who have been screened.

4.9 Departure lounge

The departure lounge is known as an area that gathers and assembles passengers prior to their flight, allowing them to wait for their boarding time. It is usually designed to contain some boarding passengers before their departure (in 15 min), with the assumption that is the aircraft boarding time for the aircraft. The lounge should have the capacity for hosting these waiting passengers despite the fact that not all will need to wait there. Sophisticated procedures for planning departure lounges have been talked about in Wirasinghe and Shehata (1989) and de Barros and Wirasinghe (2002). It is a necessity to permit only checked-in passengers in these lounges.

4.10 Circulation areas

Commonly, the circulation area component is taken into account as an issue and analysed using measures and standards, such as those offered by IATA (International Air Transport Association, 2004). The passenger's walking distance, the pace, the number of changed level and the level of interference the passenger comes across while walking are important measures in the evaluation of this area.

4.11 Concessions

Seneviratne and Martel (1991) discovered that approachability to services and facilities is the second most important indicator of performance in waiting areas in their passenger survey. The survey included rest rooms, restaurants and retail outlets.

4.12 Walking distance

One of the things that is least understood is the effect of walking in terminals, found to be the most significant and most controversial aspect. In some airports, walking distances, particularly for transfer travellers, turn out to be very long. Numerous analysts have utilized it as a critical measure of LOS or the level of service for a terminal: de Barros and Wirasinghe (2003), de Neufville et al. (2002), Correia (2008a, 2008b), Bandara and Wirasinghe (1992) and Seneviratne and Martel (1991). In spite of the fact that its significance as a measure is known, there is no valid study to assess the influence of the walking distance on the LOS by considering passenger opinions.

4.13 Orientation

Hart (1985) defined orientation as a passenger's discernment of nearby positions while passing through whether on foot or using a supporting object like a car. Passenger dissatisfaction, inconvenience, disappointment, frustration and delays are some observed consequences of airport poor orientation systems. Obviously, there is a relationship between orientation and walking distance. Progressed methodologies for measuring orientation have been suggested by Dada and Wirasinghe (1999). An essential methodology for measuring the LOS orientation has been offered by Dada and Wirasinghe (2002).

4.14 Total time

Lowering travel time between departure point and destination location is the primary playing point of air transportation compared with other modes of long distance transportation. Summation of access time, terminal time and airtime generates the total travel time. The access time is an issue, which has a high significance. In some incidents, the access time goes beyond the air time (for example on a 500km flight between two large city airports, the time spent in the airports can be twice the air journey).

4.15 Theoretical framework

It is helpful to examine the diverse hypotheses on which the methodology for overall LOS can be built as it is inspired by Correia et al. (2008a) and Correia et al. (2008b). For a weighted average methodology it is expected that travellers consolidate their encountered observation at diverse terminal segments into a weighted average of individual LOS. A key step in this strategy is deciding the weights connected with each one segment, which means, their comparative significance as appointed by travellers. These weights are of high significance for operation supervisors and planners, in light of the fact that they will permit them to centre their consideration on the most significant segments.

By applying this consideration, an awful traveller encounter in a given segment might be offset by a great encounter in a different one. An additional method that could be used for overall LOS assessment is dependent upon the greatest LOS assessment. Thus, it is expected that travellers assess the overall terminal LOS as stated by the greatest LOS value encountered in any of the terminal segments. Bearing that in mind, a traveller encountering LOS A at passport check, however LOS C for all remaining segments, will even now appoint LOS A to the overall terminal level of service.

The inverse of this methodology is to accept that travellers assess their overall terminal LOS as stated by the worst encounter they confront. For example, if a traveller encounters LOS A for all segments, with the exception of baggage claim, where encounters a LOS E, overall terminal experience will be assessed as LOS E.

In spite of the fact that these two assumptions are basic in nature, they speak to elective ideas to the weighted normal methodology, which needs data (weights) that are not easy to accumulate. A change to the greatest and least LOS methodologies might be utilizing noticeable measures of LOS, for example, mode, average or mean. Assume for terminal segments, we can get a vector speaking to LOS assessments for all the distinctive parts, e.g.,
V :(A, C, D, A, A, B, D, A)
This vector could deliver LOS assessments for an arriving path:
Passport check (LOS A), baggage claim (LOS C), X-ray (LOS D), etc.

The most used value found in the above vector is LOS A (four times), which can be the modal value. The average is between A and B, and the mean may be calculated just if numerical qualities are given out to the letters. By chance, LOS A is additionally the greatest LOS value yet that may not be the situation for different cases.

The minimum quality (LOS D) is a long way from the mode and happens for only two segments. The injustice of applying the base LOS value method for this assessment is obvious, particularly if the part spoken about by LOS D is not "that significant " as stated by client observations. The mode, average and mean quality methodology can likewise show disapproval dependent upon a relative weight viewpoint; the facts may prove that the most used LOS value really speaks about segments that do not have high weights as stated by travellers' opinions.

In spite of the fact that the weighted average methodology is more sophisticated, requiring data that are generally not easy to acquire, it has the ability to speak about an adjusted and satisfactory overall LOS assessment. This is the methodology utilized as a part of this chapter. In this manner, a suitable approach needs to be advised to focus the relative weights of distinctive parameters from the client's perspective.

4.16 Additive approach

The additive approach is used for acquiring the composite equations expressing the overall level of service for the inspected terminal. By applying this approach, the composite comparison might be created as:

$$\mathrm{LOS(Overall)} = \sum \mathrm{w_i}\ \mathrm{LOS(X_i)} \qquad (4.1)$$

Where w_i are positive weights around the terminal parts or segments and characteristics, X_i (passport check counter, baggage claim, total time, walking distance, and so on). This function facilitates the divided contributions of the distinctive attributes to acquire the collective level of service assessment. It is the most recognized of the multi-quality representations, and it is dominant due to its significance to some genuine issues and its relative unfussiness (Keeney and Raiffa, 1976). It has to be said that the utilization of the weighting plan is conceivable if certain associations are found. These are identified to be the idea of worth independence and are characterized by the associated explanations (Pardee et al., 1969):

The relative significance of fulfilling separate qualities or attributes does not rely on the different levels to which every attribute has itself been fulfilled. Noticeably, their relative significance is considered as being steady in this matter. The specific rate at which improved fulfilment or satisfaction of any given characteristic or attribute helps total value is independent of the level of satisfaction attained on that and different characteristics. Such rates are viewed as steady. The rate at which management might be ready to swap reduced satisfaction on a single characteristic or attribute for improved satisfaction on different attributes, to protect the same overall satisfaction value, is independent of the level of satisfaction already attained by some or every characteristic or attribute.

There are a few methodologies that could be useful to check whether the illustrative variables are additive independent and if each two qualities or attributes are irrelevant of each other's. Utilization of examination of association will be made between variables to focus on the level of multi-collinearity between them as suggested by Miles and Shelvin (2001). Assuming that it is found that the variables are not free of one another, the examiner must deal with decreasing the dimensionality of the issue (Keeney and Raiffa, 1993)

4.17 Weighting values

Weighting functions have been applied in the earlier studies through a range of reachable techniques, including rating, ranking and pair wise comparisons. The ranking approach is helpful for getting the most essential quality in a given set. On the other hand, it is not able to give the quantitative selections to alternate characteristics. The use of this system to LOS evaluation has been examined by Müller and Gosling (1991). Another approach to work out this problem might be the use of the rating; nonetheless, it is not clear if travellers can significantly and seriously answer questions requesting them to appoint relative qualities to broadly distinctive measurements.

The pair wise approach for comparison is more mature and can conquer the challenges connected with the rating and ranking approaches as it is recognized as an analytical hierarchy process (AHP) (Taylor, 2012), (Taha, 2010).

The core of the AHP system is the report of the relative weights. Expecting that to work with n criteria, the method secures an n × n pair wise comparison lattice that reveals the decision of the relative significance of the diverse criteria. These comparisons are created utilizing a preference scale, which allocates numerical qualities to diverse degrees of preference. From the utilization of the three techniques, it is clear that the pair wise examination is likewise a great technique for acquiring significant relative weights of the segments. Nonetheless, its data requirements are huge to the point that it can be hard to implement.

The proposed approach can get weights without essentially asking travellers direct questions. This technique could be clarified by the next associated sample.
In a situational study, participants are approached to state LOS evaluations for each of the eight attributes offered (Processing time, Delay, Comfort Cleanliness, Courtesy of staff, Convenience, Information visibility, Security, Service and so on.) in addition to an overall LOS evaluation. At that point, a regression might be fitted as:

$$\mathrm{LOS(Overall)} = \mathrm{w_1 \times LOS(A_1) + w_2 \times LOS(A_2) + \cdots + w_8 \times LOS(A_8)} \qquad (4.2)$$

where LOS (overall) is overall LOS measure; $\mathrm{LOS(A_1)}$, $\mathrm{LOS(A_2)}$, ..., $\mathrm{LOS(A_8)}$ is LOS evaluations for individual components; w_1, w_2, ..., w_8 are weights. The weights, w_1, w_2, ..., w_8, are the parameters of the regression mathematical representation, which might be found by the ordinary least squares (OLS) technique. Therefore, the weights are ‘‘revealed’’ by the travellers' observations of the relative significance of each element.

4.18 Data collection

A comprehensive traveller survey was carried out keeping in mind the aim to acquire participant observation upon the level of service. A revealed preference procedure was utilized, implying that the inquiries concerned the assessment of real encountered experiences. Questionnaires and interviews were done in the terminal plaza, just minutes after the experience of the arrival passenger flow process.

4.19 Questionnaires

A set of logical steps that should be adapted to create a high-quality questionnaire, as proposed by Aaker et al. (1998), was taken into consideration. A review was made of various airport studies through some journals (Lemer, 1988; Airports Council International, 2000; Correia et al., 2008a; Correia et al., 2008b). A pilot study was done and feedback taken from academia and participants at the King Abdul-Aziz international airport - Hajj terminal. A few alterations were prepared, and the enhanced survey was carried out in the end of the year 2011(end of 1432 Hijri year) on the 11th and 12th of the Hijri year.

Essential improvements are considered such that few variables are required to be available in the LOS assessment and trimming spent in each component or segment. These modified variables were ideas given by the passengers to the survey conductor: These variables were recommendations made via airstrip clients to the questioners: getaway time, total delay in the terminal, and vaccine time.

4.20 Case study of Hajj terminal at King Abdul-Aziz Airport international airport

King Abdul-Aziz international airport handled almost 18 million passengers in 2012 (jed-airport.com), making it one of the busiest airports in the Middle East. The design view of the terminal buildings is presented in Figure 4.3- Figure 4.5. The terminal buildings are designed as five modules with ten jet ways first one is equipped for airbus 380. There are some commercial stores and services, such as restaurants and banks, in the Plaza area.

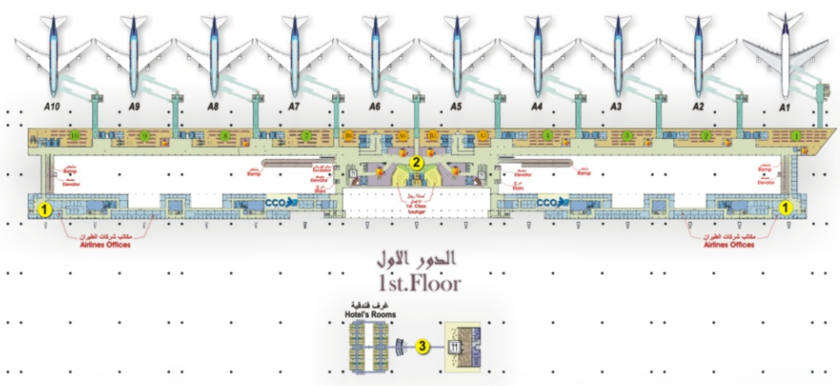


Figure 4.5 First floor layout of the Hajj terminal buildings

4.21 Summary of responses

A hundred passengers were interviewed in a survey at the Hajj terminal of King Abdul-Aziz international airport; the survey was carried out in October 2011. The pilot survey was carried out initially, where 19 passengers were interviewed. Passengers were interviewed after their arrival at the end of the process. All the passengers were international travellers and intending to perform Hajj in Makkah. The result is presented in percentages as shown in Table 4.1.

Table 4.1 Table Distribution of responses in the Hajj terminal.

Category	*1-unacceptable*	*2-poor*	*3-regular*	*4-good*	*5-excellent*
1. Processing time in the airport terminal	0	0	42.9	35.7	21.4
2. Delay in the airport terminal	7.1	3.57	39.3	32.1	17.9
3. Comfort Cleanliness in the airport terminal	3.6	7.14	21.4	35.7	32.1
4. Courtesy of staff in the airport terminal	3.7	3.7	22.2	44.4	25.9
5. Convenience in the airport terminal	0	22.2	25.9	29.6	22.2
6. Information visibility	0	14.8	22.2	48.2	14.8
7. Security	0	0	18.5	48.2	33.3
8. Service	0	11.1	11.1	55.6	22.2
9. Overall LOS	0	2.38	35.7	45.2	16.7

Out of the total passengers, 89% were male and 11% were female. A Minor portion of results (8) were found to be insufficient and removed from the calculation. It can be seen from Figure 4.6 that the LOS evaluations are not uniform along with different characteristics. Nonetheless, the overall LOS evaluations are approximately relative to each LOS attribute. This relativity implies that the hypotheses proposed may be logical. After that, the relationship function is explained and identified.

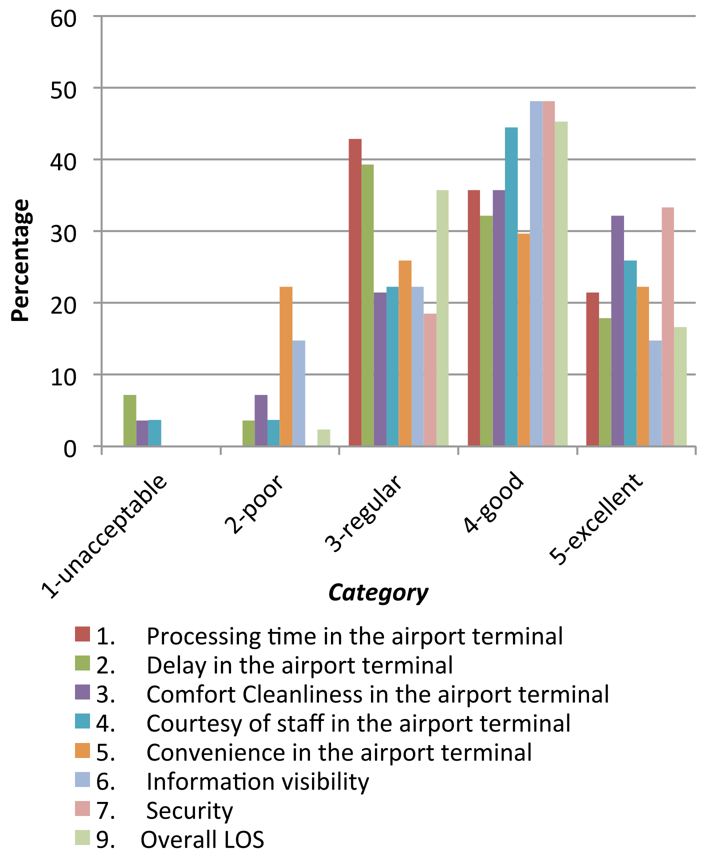


Figure 4.6 Percentage of terminal rating responses. Categories (LOS Ratings): 1-unacceptable; 2-poor; 3-regular; 4-good; 5-excellent.

4.22 Data analysis

As earlier assumed, an examination will be performed between the overall LOS passenger evaluations (1–5) and LOS passenger evaluations (1–5) for distinct parts and qualities by regression. However, a few from the earlier process must be remade. This process incorporates adapting a statistical study to verify the in-between correlations, the importance of parameters, and the fitness of the model.

4.23 Correlation among variables

An issue regularly experienced in multi regression is multi-collinearity, or the measure of ‘‘overlapping’’ data about the dependent variable that is given by a few independent variables (Taylor, 2012). This issue normally happens at the time when the independent variables are strongly connected or correlated. The relationship variable determines the level of collinearity between two factors. A perfect (linear) negative relationship occurs if the correlation equals -1; on the other hand a perfect (linear) positive relationship happens if the correlation equals +1. Nonlinear relations can be represented with a correlation of 0 as correlations between all rating measures using Pearson correlation are illustrated in table 4.2.

Table 4.2 Correlations between all rating measures using Pearson correlation.

		Processing time	*Delay*	*Comfort Cleanliness*	*Courtesy of staff*	*Convenience*	*Information visibility*	*Security*	*Service*	*Overall LOS*
Processing time	Pearson Correlation	1	.527**	.224*	.589**	.579**	.403**	.327**	.287**	.713**
	Sig. (2-tailed)		0	0.04	0	0	0	0	0.009	0
	N		84	84	81	81	81	81	81	84
Delay	Pearson Correlation		1	-0.064	.432**	.480**	.427**	0.19	-0.06	.543**
	Sig. (2-tailed)			0.563	0	0	0	0.08	0.611	0
	N			84	81	81	81	81	81	84
Comfort Cleanliness	Pearson Correlation			1	.545**	.292**	.322**	.516**	0.14	.332**
	Sig. (2-tailed)				0	0.008	0.003	0	0.214	0.002
	N				81	81	81	81	81	84
Courtesy of staff	Pearson Correlation				1	.468**	.568**	.628**	.461**	.606**
	Sig. (2-tailed)					0	0	0	0	0
	N					81	81	81	81	81
Convenience	Pearson Correlation					1	.656**	.489**	.260*	.562**
	Sig. (2-tailed)						0	0	0.019	0
	N						81	81	81	81
Information visibility	Pearson Correlation						1	.491**	.368**	.450**
	Sig. (2-tailed)							0	0.001	0
	N							81	81	81
Security	Pearson Correlation							1	.567**	.467**
	Sig. (2-tailed)								0	0
	N								81	81
Service	Pearson Correlation								1	0.16
	Sig. (2-tailed)									0.155
	N									81

**. Correlation is significant at the 0.01 level (2-tailed).
*. Correlation is significant at the 0.05 level (2-tailed).

The addition or subtraction of variables should be made carefully. A model can turn out to be non-representative for the reason that significant variables are counted or unacceptably taken out. Furthermore, every airport might have a distinctive model requirement, which can be a function of financial, operational and socio-economic attributes. The connection between these attributes variables is significant, yet it is not by any means the only criterion for addition or subtraction of those variables in the model.

The greatest correlation value was located between the evaluations of overall LOS and processing time. The cause behind this is that arrival travellers take a long time during their flight journey and the airport handles a high capacity of international passengers. There are additionally quite strong correlations found between the courtesy of staff and security, between overall LOS and courtesy of staff and between information visibility and convenience.

4.24 Composite evaluation

The evaluations of the attributes are collected as:

$$\mathrm{LOS(Overall)} = \mathrm{w_0} + \mathrm{w_1}\times\mathrm{LOS(Processing\ time)} + \mathrm{w_2}\times\mathrm{LOS(Delay)} + \mathrm{w_3}\times\mathrm{LOS(Comfort\ Cleanliness)} + \mathrm{w_4}\times\mathrm{LOS(Courtesy\ of\ staff)} + \mathrm{w_5}\times\mathrm{LOS(Convenience)} + \mathrm{w_6}\times\mathrm{LOS(orientation)} + \mathrm{w_7}\times\mathrm{LOS(Security)} + \mathrm{w_8}\times\mathrm{LOS(Service)} \tag{4.3}$$

Where LOS (overall) is overall airport terminal LOS evaluations; LOS (Processing time), LOS(Delay), LOS(Comfort Cleanliness), LOS (Courtesy of staff), LOS (Convenience), LOS (orientation and Information visibility), LOS (Security) and LOS (Service) is LOS evaluations for every single characteristic or attribute; w_0 is intercept; and w_1, w_2, w_3, w_4, w_5, w_6, w_7 and w_8 are coefficients or parameters of the mathematical equation as exposed in tables 4.3-4.6 out of the SPSS by entering questionnaires results.

Table 4. 3 Variables Entered/Removed[b]

Model	*Variables Entered*	*Variables Removed*	*Method*
1	W1, W2, W3, W4, W5, W6, W7, W8[a]	.	Enter

a. All requested variables entered.

b. Dependent Variable: Overall

Table 4. 4 Model Summary

Model	*R*	*r Square*	*Adjusted R Square*	*Std. Error of the Estimate*
1	.838[a]	0.703	0.67	0.420

a. Predictors: W0, W1, W2, W3, W4, W5, W6, W7, W8

Table 4. 5 ANOVA[b]

Model		*Sum of Squares*	*df*	*Mean Square*	*F*	*Sig.*
1	Regression	30.117	8	3.765	21.304	.000[a]
	Residual	12.723	72	0.177		
	Overall	42.84	80			

a. Predictors: W0, W1, W2, W3, W4, W5, W6, W7, W8

b. Dependent Variable: Overall

Table 4. 6 Coefficients[a]

Model		*Unstandardized Coefficients*		*Standardized Coefficients*	*t*	*Sig.*
		B	Std. Error	Beta		
1	W0	0.465	0.369		1.262	0.211
	W1	0.562	0.09	0.607	6.275	0
	W2	0.074	0.071	0.109	1.048	0.298
	W3	0.043	0.067	0.063	0.636	0.527
	W4	0.055	0.091	0.073	0.6	0.551
	W5	0.001	0.07	0.001	0.008	0.993
	W6	0.035	0.078	0.044	0.452	0.653
	W7	0.281	0.108	0.273	2.616	0.011
	W8	-0.185	0.082	-0.222	-2.254	0.027

a. Dependent Variable: Overall

Replacing the LOS evaluations of the equation by the answers of 1–5 of the assessment done at the Hajj Terminal of King Abdul-Aziz international airport, and creating a regression study, will offer the parameter values w_1, w_2, w_3, w_4, w_5, w_6, $w_7$and w_8 as the coefficients of the regression equation, and w_0 as the constant or intercept. Thus, the coefficients are acquired, representing the passenger observations of the relative significance of elements.

The outcomes of that regression are revealed in Table 4. 3 - Table 4. 6. Statistically, it is observed from Table 4. 6 that the convenience parameter has a chance of 99% to be zero. That inspired the researcher to get rid of this attribute from the analysis. Even though it may be found to be a very essential measure for the overall airport terminal assessment, it seems that travellers at Hajj terminal of King Abdul-Aziz international airport might not consider or value this attribute.

The regression study consists of 81 perceptions. The 19 participants prepared in the pilot survey conducted at the beginning of the Hajj season are not considered for the reason that some modifications were made to the survey. The following regression will now consider these 81 participants, due to the absence of some attributes values are no more items of the overall LOS examination.

4.25 Regression with no Convenience

The table 4.7 represents the variables that were used in the multiple regression model concerning Residential Improved properties in Calumet Township

Table 4. 7 Variables Entered/Removed[b]

Model	*Variables Entered*	*Variables Removed*	*Method*
1	W1, W2, W3, W4, W5, W6, W7, W8[a]	.	Enter

a. All requested variables entered.

b. Dependent Variable: Overall

Table 4. 8 Model Summary

Model	*R*	*R Square*	*Adjusted R Square*	*Std. Error of the Estimate*
1	0.838[a]	0.703	0.675	0.417

a. Predictors: W0, W1, W2, W3, W4, W5, W6, W7, W8

Table 4. 9 ANOVA[b]

Model		*Sum of Squares*	*df*	*Mean Square*	*F*	*Sig.*
1	Regression	30.116	7	4.302	24.685	0.000[a]
	Residual	12.723	73	0. 174		
	Overall	42.840	80			

a. Predictors: W0, W1, W2, W3, W4, W5, W6, W7, W8

b. Dependent Variable: Overall

Table 4. 10 Coefficients[a]

Model		*Unstandardized Coefficients*		*Standardized Coefficients*	*t*	*Sig.*
		B	Std. Error	Beta		
1	W0	0.465	0.350		1.326	4.1.0.189
	W1	0.562	0.081	0.607	6.914	4.2.0.000
	W2	0.074	0.069	0.109	1.069	4.3.0.289
	W3	0.043	0.066	0.063	0.644	4.4.0.521
	W4	0.055	0.088	0.073	0.619	4.5.0.538
	W6	0.035	0.068	0.044	0.521	4.6.0.604
	W7	0.282	0.103	0.273	2.728	4.7.0.008
	W8	-0.185	0.081	-0.222	-2.272	4.8.0.026

a. Dependent Variable: Overall

The Hajj terminal is found to be fast enough and with no issues to travellers. The convenience element is not mandatory, and some passengers did not have a well-built judgment about its level of service because they had not encountered it. One variable was ignored in the analysis, due to the characteristics of the terminal. This was the ‘purpose’ variable; as the terminal is devoted to Hajj passengers (trip purpose is performing Hajj) usually passengers are asked whether their purpose is business, combined business/non-business or non-business, but in this case this question was not applicable.

One of the steps in refining the survey was the removal of likely outliers. The outliers were found in this survey as evaluations of participants that were obviously conflicting. It could be a passenger that assessed the overall airport terminal as 5, but assessed all or most elements as 1 or 2. Five cases showed this conflict and were ignored before the study.

The regressions without these outliers are presented in Table 4. 7 - 4.10. The weights of Table 4. 10 could be substituted into Equation 4.2 to give the following (by removing neglected part of $w_5 \times \mathrm{LOS(Convenience)}$):

$$\mathrm{LOS(Overall)} = w_0 + w_1 \times \mathrm{LOS(Processing\ time)} + w_2 \times \mathrm{LOS(Delay)} + w_3 \times \mathrm{LOS(Comfort\ Cleanliness)} + w_4 \times \mathrm{LOS(Courtesy\ of\ staff)} + w_6 \times \mathrm{LOS(orientation)} + w_7 \times \mathrm{LOS(Security)} + w_8 \times \mathrm{LOS(Service)} \quad (4.4)$$

As acknowledged by Eq 4.4, the most significant element for travellers is the processing time. That appears obvious as long flight passengers need to rest and any extra time they spend in the airport causes stress. Security is the second most significant element. The relatively low significance of the orientation, information visibility and comfort cleanliness elements, when compared to the processing time and security, can be clarified by the fact that, at the Hajj terminal in the King Abdul-Aziz international airport, travellers are accustomed to spending a long time in these latter two elements. The constant 0.465 shows that additional variables might be integrated in this study. It implies that there are elements of the overall LOS that are not denoted by the descriptive attributes integrated in the survey. It also indicates that different 'what if' scenarios and different modelling techniques, even nonlinear, might be considered like DES and ANFIS.

4.26 Summary

This chapter has produced the global index for LOS assessments at airport terminals. The key role is naming the most significant attributes by considering user experience. This study was carried out in the Hajj terminal of the King Abdul-Aziz international airport and classified the processing time among the most important measures affecting the users' observation of the level of service. This motivated a DES (discreet event simulation), that focuses on the processing time of each resource, and which is found in the next chapter. The gathered data related to time in this survey will also be included there. The outcomes of this study also point to the fact that some terminal attributes not examined in this study might have an input to the evaluation of LOS.

Chapter 5: Simulation Model

5.1 Introduction

In this chapter, all aspects of building the simulation platform are covered. This chapter starts with the simulation building methodology and processes that are adopted in this research. Then, data collection and input data analysis are prepared with the assistance of the Arena input analyser, that takes data gathered from the airport environment and the terminal data sheets. After that, flowchart modules are fully described in detail by listing the eighteen blocks that are constructed in this simulation model. The modules' descriptions are categorised by their blocks, and values for configuration are captured. The main aim of the created simulation model is to obtain the results needed for the next step of the project, which considers various simulation scenarios' inputs and presents their input-output analysis.

5.2 Simulation Methodology

The methodology presented in this chapter is inspired by the fundamental methodology behind a successful simulation project (Shannon 1998; Banks 2000; Wyland et al., 2000) as shown in Figure 5.1. Step one is based on problem classification, identifying the aims and objectives of the research. To identify the problem it is required to recognise that the process flow is known to be one of the key aspects that characterises the quality of service of airport terminal operations (Lanner, 2002). That fact is enhanced if the terminal serves as the entrance to huge events that attract a high number of travellers at a certain time, regardless of the fact that they may have different origins, cultures, languages and backgrounds. The Hajj terminal is a one-of-a-kind airport terminal that has a unique flow behaviour with two easily distinctive phases: the arrival and departure phases, segregated by a ten day period of phase transition. Airport security became critical after the 11th September incident, which can lead to more delays and cause a bottleneck in security procedure associated resources. In response to pandemic influenza, medical related processes also became crucial. Assessment can be made by creating a number of 'what if' scenarios using the Arena simulation model. The offered model aims to measure the passenger flow performance in the airport terminal and in the Hajj terminal in particular. After that, bottlenecks will be identified in the terminal before the Hajj time, and the model can offer suggestions for scenarios to make best use of the resources and reduce the queuing time. The second step focuses on project planning; allocating enough resources to perform the assigned duties. Building any Arena model needs logic analysis and converting the process flow from a continuous event simulation to a discrete event simulation. The logic has been developed starting from the planes' arrival in the jet way parking which then routes travellers to the terminal. Initially, they will be released to vaccination, where 20% of arrivals are vaccinated, as is advised by the Ministry of Health in the Kingdom of Saudi Arabia, based on reports gathered from the World Health Organization (WHO). The other 80%, joined by the vaccine-injected travellers, will be guided to168 passport check points spread over four areas (distributed 18 points, 48 points, 48 points and 18 points) as it is explained in the introduction chapter. Then the passengers are released to the baggage claim area with ten conveyor belts. After that, a shopping area is located before the customs area, which has sixteen x-ray check points placed at the exits of the four different modules A, B, D and E. Finally, travellers will be guided to the Plaza.

System characterisation and definition is the third step, knowing and setting the restrictions and boundaries to be employed in describing the process and examining how it works. The process, or system, can be characterised by identifying the boundaries and restrictions that exist in the airport resources e.g. there are ten jet ways which point to an approximate airport capacity of 10 flights per hour. Another boundary can be defined by the arrival aircraft procedure, as after arrival each plane needs two to three hours in order to release individuals and their baggage, refuel the plane, replenish catering supplies and change the flight crew. Each passenger and his luggage are labelled with identification tags, which will allow every passenger to collect his, and only his, bags. There is also another tag used to number the bag among the total bags assigned. The fourth step is conceptual or logic model generation, building an initial model either as an illustrative chart or block diagram to identify the components, variables, and relations (algorithm logic) that make up the system (see *Figure 5.2* below). This step has been described in the Flowchart Modules Description section.

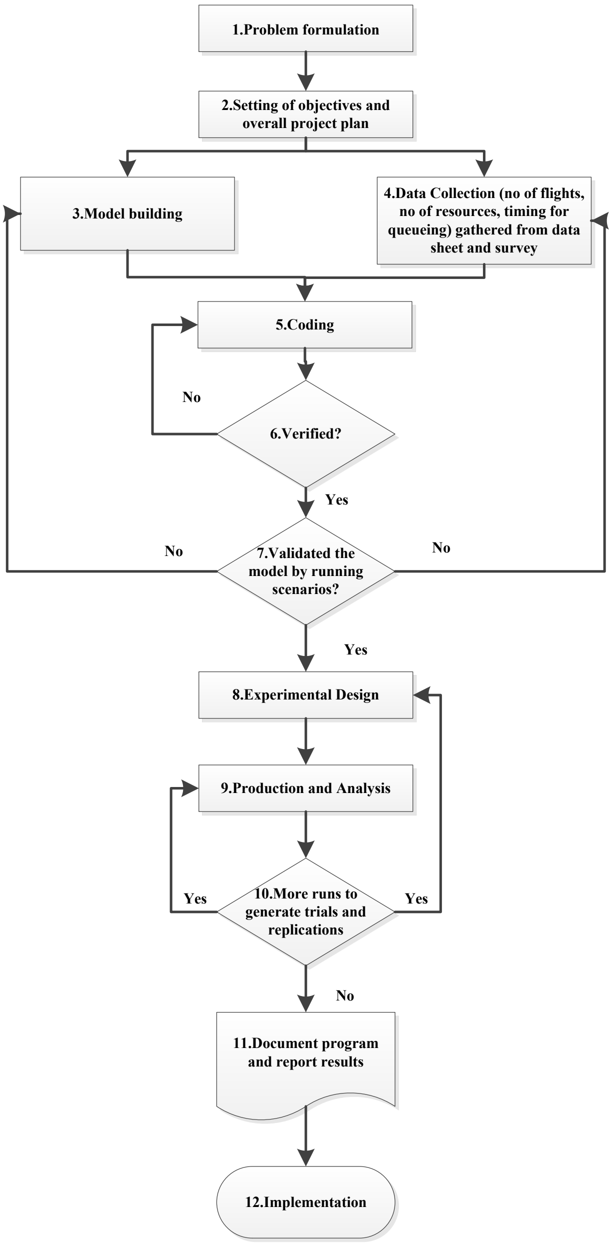


Figure 5.1 Steps in a Simulation Study (Banks 2000)

The simulation model logic is created on 18 blocks with more than a thousand elements which include modules resource variables and others. The initial experimental proposed design is the fifth step, determining which data is required to be collected from the simulation model, in which form, and to what extent. This step essentially has been implemented as the actual data is added to the model and output was checked with actual gathered information from both passengers and the airport authority. The data analysis was used to prepare the input in expression form so that Arena could carry out the simulation. Preparing input data is the sixth step, defining and gathering the data needed for the model. This was done by carrying out a survey with arrived passengers, during a meeting with the airport authority staff, and by observing the process flow. MTR or minimum technical requirement is the main measure used in the company assessment. Model interpretation or translation is the seventh step, putting up a structure for the model in a suitable simulation language.

This stage has been described in the Flowchart Modules Description which is explained later in this chapter (see Section 5.6). Elements such as variables, expressions, attributes, modules and resource sets are employed together to describe the system and procedures in the airport terminal operations in the suggested simulation model logic. Rockwell Arena software was utilised as high level programming language to build up the proposed model in a proper simulation mode. To prepare verification and validate the model is the eighth step, verifying that the model functions in a manner that the analyst aimed for (debugging) and that the results of the model are reasonable and reflect the numbers of the actual system. This part has been included in the seventh chapter. Final testing of the design is the ninth step, examining that will produce the required information and finding out how every test runs. This step can be seen in the offered 249 scenarios made by changing variables. However, more scenarios can be offered for other terminals to generate a more global model. Experimentation is the tenth step, carrying out the simulation to produce the required data and present a regression analysis. This has been looked at broadly in the sixth chapter. Analysis is the eleventh step, drawing a chart from the data collected from the simulation and carrying out further analysis and regression to allow optimisation for the system. This step has been illustrated as two main mathematical representations in the findings and analysis later in the seventh chapter. Finally, documentation and implementation are the twelfth step, “putting the results to use”, using the findings to do optimisation on the generated mathematical representation, which can be seen in this thesis.

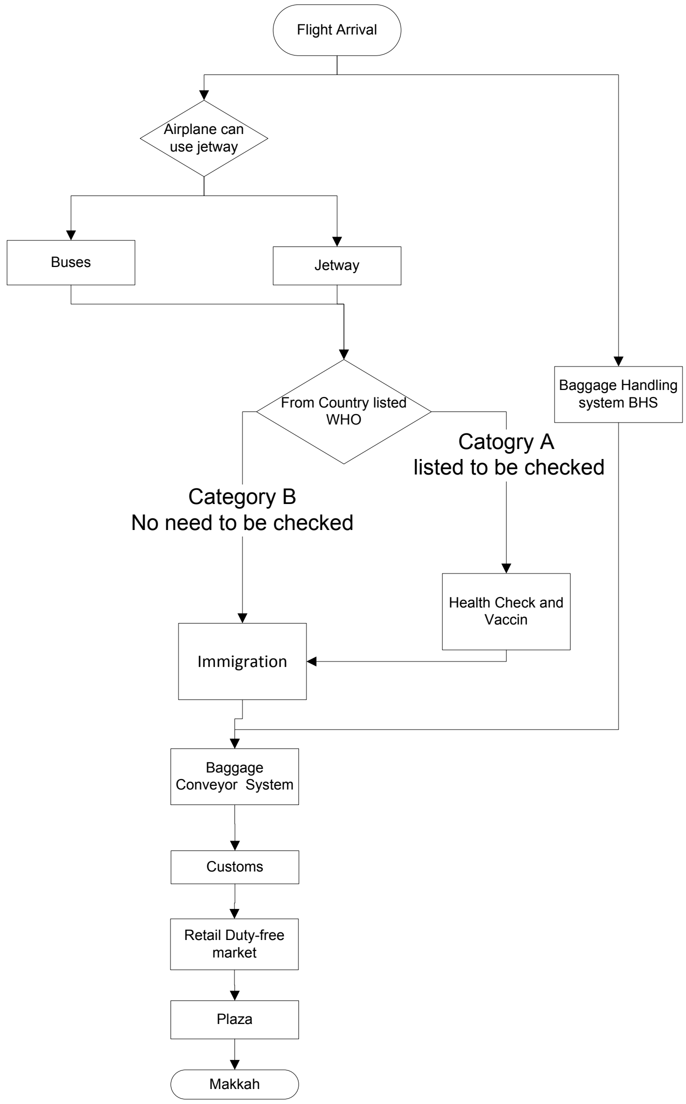


Figure 5.2 Arrival Passenger flow chart

5.3 Data collection and input data analysis

Data collection is an essential piece of the work since it involves full awareness of the system, which can be attained with cooperation involving organisations who value the research role and development of the organisation measures. The PPMDC is one of those companies which allows such studies and has assisted this study to approach its aims by the data gathered. The collected data can be classified as entity-related data and resource-related data; the first is normally more reachable as the figure of arriving flights is easily accessed. The other parts of the data can be measured from samples surveyed and timed for some passengers at various periods of time. Table 5.1 shows arrival details of Hajj terminal's flights for the year 2013 and 2008.

Table 5.1 Years 2013 and 2008 Hajj Terminal actual flight arrival schedule table.

	2013			2008		
		All terminals			All terminals	
			Subtotal			Subtotal
	DATE	Flights	Passengers	*DATE*	Flights	Passengers
1	**07-Sep-13**	20	2,524	**01-Oct-08**	65	8,515
2	**08-Sep-13**	32	4,465	**01-Nov-08**	34	4,989
3	**09-Sep-13**	49	8,558	**02-Nov-08**	45	9,281
4	**10-Sep-13**	56	11,457	**03-Nov-08**	42	9,108
5	**11-Sep-13**	54	13,003	**04-Nov-08**	37	7,395
6	**12-Sep-13**	51	12,016	**05-Nov-08**	54	11,452
7	**13-Sep-13**	54	13,461	**06-Nov-08**	61	13,095
8	**14-Sep-13**	53	11,665	**07-Nov-08**	54	11,862
9	**15-Sep-13**	55	11,851	**08-Nov-08**	62	13,514
10	**16-Sep-13**	63	14,584	**09-Nov-08**	63	15,293
11	**17-Sep-13**	62	13,023	**10-Nov-08**	65	15,581
12	**18-Sep-13**	53	12,271	**11-Nov-08**	62	12,883
13	**19-Sep-13**	67	13,878	**12-Nov-08**	77	17,038
14	**20-Sep-13**	67	12,400	**13-Nov-08**	86	17,792
15	**21-Sep-13**	68	14,194	**14-Nov-08**	94	22,172
16	**22-Sep-13**	75	14,158	**15-Nov-08**	122	27,920
17	**23-Sep-13**	76	15,553	**16-Nov-08**	112	26,075
18	**24-Sep-13**	90	16,998	**17-Nov-08**	133	30,484
19	**25-Sep-13**	117	22,542	**18-Nov-08**	133	32,255
20	**26-Sep-13**	135	28,716	**19-Nov-08**	167	40,624
21	**27-Sep-13**	151	32,808	**20-Nov-08**	189	44,962
22	**28-Sep-13**	134	29,371	**21-Nov-08**	186	43,789
23	**29-Sep-13**	142	30,522	**22-Nov-08**	197	46,196
24	**30-Sep-13**	156	33,942	**23-Nov-08**	225	52,913
25	**01-Oct-13**	179	39,018	**24-Nov-08**	219	50,389
26	**02-Oct-13**	191	39,708	**25-Nov-08**	215	49,462
27	**03-Oct-13**	184	38,748	**26-Nov-08**	236	54,384
28	**04-Oct-13**	196	41,915	**27-Nov-08**	257	61,305
29	**05-Oct-13**	203	44,926	**28-Nov-08**	258	61,775
30	**06-Oct-13**	195	43,623	**29-Nov-08**	234	57,070
31	**07-Oct-13**	213	47,314	**30-Nov-08**	261	64,587
32	**08-Oct-13**	219	48,957	**01-Dec-08**	256	62,985
33	**09-Oct-13**	249	60,142	**02-Dec-08**	254	59,809
34	**10-Oct-13**	77	11,317	**03-Dec-08**	132	26,773
35	**11-Oct-13**	40	2,073	**04-Dec-08**	112	21,610
36	**12-Oct-13**	36	517	**05-Dec-08**	29	4277
37	**13-Oct-13**	26	269			
38	**14-Oct-13**	5	56			
	TOTAL	**3,893**	**812,543**	TOTAL	**4,828**	**1,109,614**

5.4 Input related data collection and analysis

At the start, the total number of flight arrivals has been gathered from Table 5.1 and inserted into the Arena "input analyser". It fits with options performed for the analysis as shown in Figure 5.3 and Figure 5.4 as they present the distribution of arrived flights per day.

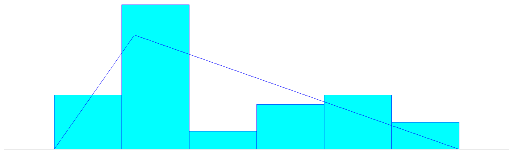


Figure 5.3 Year 2013 Hajj Flights Input analysis using input analyser

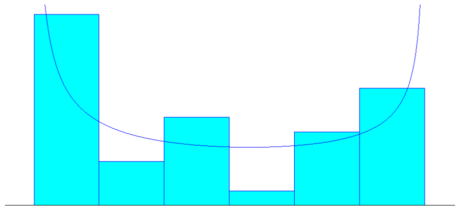


Figure 5.4 Year 2008 Input analysis using input analyser

The arrival flow follows a beta distribution expression of (29 + 232 x BETA(0.477, 0.576)) in year 2008 and triangular distribution expression TRIA(5, 53.3, 249) for year 2013. This represents the arrivals per day; to modify that to the time period between arrivals per hour the generated figure should be divided by 24 in the expression which illustrates the number of flights per day since the terminal operates 24/7 during the Hajj period. Consequently, the arrival distribution expressions are: 24/(29 + 232 x BETA(0.477, 0.576)) and 24/(TRIA(5, 53.3, 249)). Table 5.2 and Table 5.3 contain more details of the expression and its numerical characteristics. Chi square test is test is used to express whether there is a significant variance between the expected and observed frequencies in one or more categories where Kolmogorov–Smirnov test used to compare a sample with a reference probability distribution (Sheskin, 2003).

Table 5.2 year 2008 Distribution Summary details of the arrival expression

Distribution	Beta
Expression: 29 + 232 * BETA(0.477, 0.576)	
Square Error	0.013831
Chi Square Test	
Number of intervals	=4
Degrees of freedom	=1
Test Statistic	=0.808
Corresponding p-value	=0.398
Kolmogorov-Smirnov Test	
Test Statistic	0.12
Corresponding p-value	> 0.15
Data Summary	
Number of Data Points	=36
Min Data Value	=29
Max Data Value	=261
Sample Mean	=134
Sample Std Dev	=80.6
Histogram Summary	
Histogram Range	=29 to 261
Number of Intervals	=6

Table 5.3 year 2013 Distribution Summary details of the arrival expression

Distribution:	Triangular
Expression:	TRIA(5, 53.3, 249)
Square Error:	0.056310
Chi Square Test	
Number of intervals	= 5
Degrees of freedom	= 3
Test Statistic	= 10.4
Corresponding p-value	= 0.0169
Kolmogorov-Smirnov Test	
Test Statistic	= 0.199
Corresponding p-value	= 0.0896
Data Summary	
Number of Data Points	= 38
Min Data Value	= 5
Max Data Value	= 249
Sample Mean	= 102
Sample Std Dev	= 67.4
Histogram Summary	
Histogram Range	= 5 to 249
Number of Intervals	= 6

Number of travellers per flight can be measured in average from the same table (Table 5.2 and Table 5.3) by simple division of the total number of passengers per day by the total number of flights per day. Table 5.4 is created to be an input to the Arena input analyser.

Table 5.4 Year 2008 and 2013 Input average no of passenger per arrival flight

	2013			2008
	DATE	**PAX/FLT**	**DATE**	**PAX/FLT**
1	7-Sep-13	126	1-Oct-08	131
2	8-Sep-13	140	1-Nov-08	147
3	9-Sep-13	175	2-Nov-08	206
4	10-Sep-13	205	3-Nov-08	217
5	11-Sep-13	241	4-Nov-08	200
6	12-Sep-13	236	5-Nov-08	212
7	13-Sep-13	249	6-Nov-08	215
8	14-Sep-13	220	7-Nov-08	220
9	15-Sep-13	215	8-Nov-08	218
10	16-Sep-13	231	9-Nov-08	243
11	17-Sep-13	210	10-Nov-08	240
12	18-Sep-13	232	11-Nov-08	208
13	19-Sep-13	207	12-Nov-08	221
14	20-Sep-13	185	13-Nov-08	207
15	21-Sep-13	209	14-Nov-08	236
16	22-Sep-13	189	15-Nov-08	229
17	23-Sep-13	205	16-Nov-08	233
18	24-Sep-13	189	17-Nov-08	229
19	25-Sep-13	193	18-Nov-08	243
20	26-Sep-13	213	19-Nov-08	243
21	27-Sep-13	217	20-Nov-08	238
22	28-Sep-13	219	21-Nov-08	235
23	29-Sep-13	215	22-Nov-08	234
24	30-Sep-13	218	23-Nov-08	235
25	1-Oct-13	218	24-Nov-08	230
26	2-Oct-13	208	25-Nov-08	230
27	3-Oct-13	211	26-Nov-08	230
28	4-Oct-13	214	27-Nov-08	239
29	5-Oct-13	221	28-Nov-08	239
30	6-Oct-13	224	29-Nov-08	244
31	7-Oct-13	222	30-Nov-08	247
32	8-Oct-13	224	1-Dec-08	246
33	9-Oct-13	242	2-Dec-08	235
34	10-Oct-13	147	3-Dec-08	203
35	11-Oct-13	52	4-Dec-08	193
36	12-Oct-13	14	5-Dec-08	147
37	13-Oct-13	10	-	-
38	14-Oct-13	11	-	-
	Total Average	209	**Total Average**	230

The best-fit expression of the average entities by using average number of passengers per flight as input to the Arena input analyser follows Beta distribution behaviour with a mean of 220 for year 2008 and 188 for year 2013 and standard deviation of 28 and 63.3 respectively as shown in Figure 5.5 and Figure 5.6.

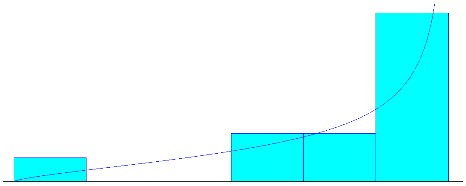


Figure 5.5 Average no of passenger per arrival flight Year 2008

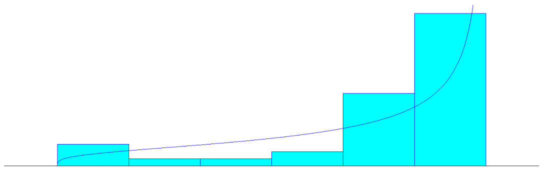


Figure 5.6 Average no of passenger per arrival flight Year 2013

Each produced expression is used to create the number of the passengers per flight by (duplicate module) as it can be used in the simulation model design phase. The distribution summary full details are listed below in Table 5.5 and Table 5.6.

Table 5.5 Details of number of passengers per flight expression 2013 - Distribution Summary

Distribution:	**Beta**
Expression: 10 + 240 * BETA(1.27, 0.441)	
Square Error:	0.029222
Chi Square Test	
Number of intervals	= 3
Degrees of freedom	= 0
Test Statistic	= 1.48
Corresponding p-value	< 0.005
Kolmogorov-Smirnov Test	
Test Statistic	= 0.276
Corresponding p-value	< 0.01
Data Summary	
Number of Data Points	= 38
Min Data Value	= 10.3
Max Data Value	= 249
Sample Mean	= 188
Sample Std Dev	= 63.7
Histogram Summary	
Histogram Range	= 10 to 250
Number of Intervals	= 6

Table 5.6 Details of number of passengers per flight expression 2008 - Distribution Summary

Distribution:	**Beta**
Expression: 131 + 117 * BETA(1.66, 0.519)	
Square Error:	0.018081
Chi Square Test	
Number of intervals	= 3
Degrees of freedom	= 0
Test Statistic	= 1.58
Corresponding p-value	< 0.005
Kolmogorov-Smirnov Test	
Test Statistic	= 0.17
Corresponding p-value	> 0.15
Data Summary	
Number of Data Points	= 36
Min Data Value	= 131
Max Data Value	= 247
Sample Mean	= 220
Sample Std Dev	= 28
Histogram Summary	
Histogram Range	= 131 to 248
Number of Intervals	= 6

5.5. Data collection of similar process in different time and analysis

This exposes data gathered for the processes themselves but in another season (not Hajj time but in Umrah time) which the operator has reserved as a measure of performance. The regulations remain the same as during Hajj time as it is critical with 70,000 passengers per day to pressure airline, handling and catering companies to be as fast as possible with their work, to allow arrival of more flights; otherwise buses are available as an alternative to the jet ways if all jet ways are in use simultaneously. This relies on the data sheets supplied by the airport terminal management company. The input analyser was used here to analyse the time required to simulate the parking time of the plane in the jet way as is illustrated in Figure 5.7 which shows the distribution of measured timing taken for using a particular jet way.

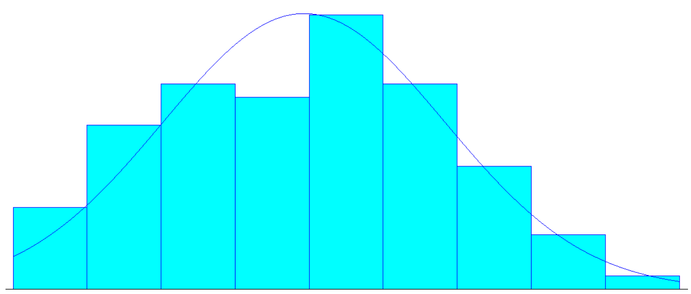


Figure 5.7 Airplane parking time in the jet way.

This parking time allows passengers and luggage to be released to the terminal to complete their arrival process, lets the crew be changed and makes sure that the plane is prepared and ready to fly again. Plane fuelling time to next destination is usually included in that time. Restrictions enforced by the airport authority will allow the plane to stay for 3 hours as a maximum and a late fee is charged for any exceeding time. The time is illustrated by normal distribution with sample mean of 2.22 hours represented as NORM(2.22, 0.592) as shown in Table 5.7.

Table 5.7 Distribution Summary of Airplane parking time in the jet way

Distribution:	**Normal**
Expression:	NORM(2.22,
Square Error:	0.004828
Chi Square Test	
Number of intervals	6
Degrees of freedom	3
Test Statistic	3.7
Corresponding p-	0.309
Kolmogorov-Smirnov	
Test Statistic	0.0654
Corresponding p-	> 0.15
Data Summary	
Number of Data Points	96
Min Data Value	1.1
Max Data Value	3.55
Sample Mean	2.22
Sample Std Dev	0.595
Histogram Summary	
Histogram Range	= 1 to 3.8
Number of Intervals	9

The time taken from the moment the passengers are released from the aircraft until they reach the immigration area is presented in Figure 5.8.

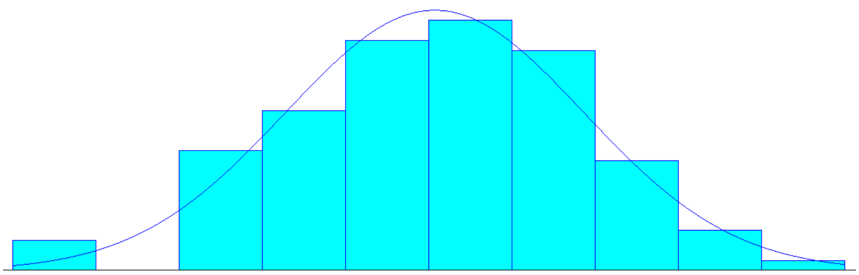


Figure 5.8 Passengers time from the jet way to immigration stations.

Passengers pass by the jet gate and are forwarded to the passport check points (immigration). The time is illustrated as a normal distribution expression with a sample mean of 3.54. The detailed summary can be found in Table 5.8.

Table 5.8 Passengers time from the jet way to immigration stations

Distribution:	**Normal**
Expression:	NORM(3.54, 0.897)
Square Error:	0.002871
Chi Square Test	
Number of intervals	6
Degrees of freedom	3
Test Statistic	0.833
Corresponding p-value	> 0.75
Kolmogorov-Smirnov Test	
Test Statistic	0.0346
Corresponding p-value	> 0.15
Data Summary	
Number of Data Points	117
Min Data Value	1
Max Data Value	5.55
Sample Mean	3.54
Sample Std Dev	0.901
Histogram Summary	
Histogram Range	= 0.999 to 6
Number of Intervals	10

Passport check and control is one of the essential elements in the passengers' arrival process flow. The immigration department in the Ministry of Interior's duty is to grant and authorise only permitted entry to the country. Finger print scanning is used for each passenger as shown in Figure 5.9.

Hajj & Ummrah analyzing weekly Report
May, 2011

Immigration Arrival (Statistic)
Saturday 07/05/2011

(Statistic Per passenger)

#	Flight #	Counters #	sex	Actual Time For Queuing Until Counters		MTR	Actual Processing Time At The Counters		MTR	Total staff	Remarks
				Start	Complete		Start	Complete			
1	SV 2887	2	M	02:50	03:23	30 minute	03:25	03:31	118 Sec	3	----------
Total Time				33 Min			6 Min				
2	IR 2649	2	F	03:40	04:15	30 minute	04:18	04:22	118 Sec	4	----------
Total Time				35 Min			4 Min				
3	W5 5094	2	F	12:08	12:44	30 minute	12:46	12:50	118 Sec	5	----------
Total Time				36 Min			4 Min				

(Statistic Per Flight)

#	Flight #	Counters #	Total PAX	Actual Time For Queuing Until Counter		MTR	Actual Processing Time At The Counter		MTR	Total staff	Remarks
				Start	Complete		Start	Complete			
1	SV 2887	2	294	02:15	03:40	Max 30 min. per passenger	02:17	03:45	Max 118 sec. per passenger	3	----------
Total Time				01:25 Hrs.			01:27 Hrs.				
Average Time Per Passenger				17 Sec.			17 Sec.				
Total Time For All Flight				01:30 Hrs.							
2	IR 2649	2	429	03:40	04:40	Max 30 min. per passenger	03:50	04:42	Max 118 sec. per passenger	4	----------
Total Time				01:00 Hrs.			52 Min.				
Average Time Per Passenger				8 Sec.			8 Sec.				
Total Time For All Flight				01:02 Hrs.							
3	W5 5094	2	441	12:08	13:28	Max 30 min. per passenger	12:14	13:31	Max 118 sec. per passenger	5	----------
Total Time				01:20 Hrs.			01:07 Hrs.				
Average Time Per Passenger				8 Sec.			8 Sec.				
Total Time For All Flight				01:23 Hrs.							

M.Mirah Page 4 of 35

Figure 5.9 immigration arrival time statistic from Ummrah report 2011

After entering the gathered data into the Arena input analyser and using the best fit option as shown in Figure 5.10, the distribution follows a normal distribution.

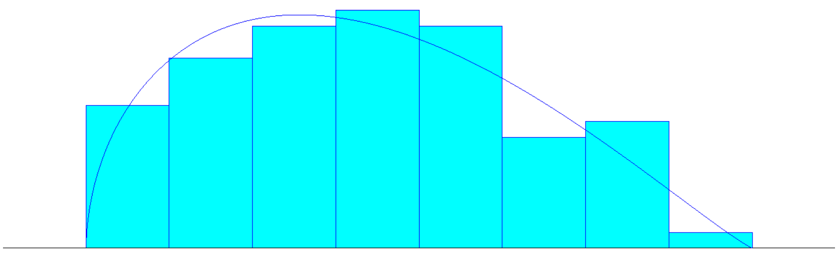


Figure 5.10 Passengers time spent in immigration stations.

The sample mean is 4.07 and standard deviation 1.13. Table 5.9 displays the detailed summary for the time needed for that process, expressed as 2 + 4.95 x BETA(1.53, 2.14).

Table 5.9 Distribution Summary of Passengers time from the jet way to vaccine and immigration stations

Distribution:	**Beta**
Expression:	2 + 4.95 * BETA(1.53, 2.14)
Square Error:	0.002954
Chi Square Test	
Number of intervals	= 6
Degrees of freedom	= 3
Test Statistic	= 1.16
Corresponding p-value	> 0.75
Kolmogorov-SmirnovTest	
Test Statistic	= 0.0903
Corresponding p-value	> 0.15
Data Summary	
Number of Data Points	= 80
Min Data Value	= 2
Max Data Value	= 6.5
Sample Mean	= 4.07
Sample Std Dev	= 1.13
Histogram Summary	
Histogram Range	= 2 to 6.95
Number of Intervals	= 8

Luggage transferring time is another input that is considered in this simulation and Figure 5.11 illustrates distribution of passengers time spent in the luggage claim area.

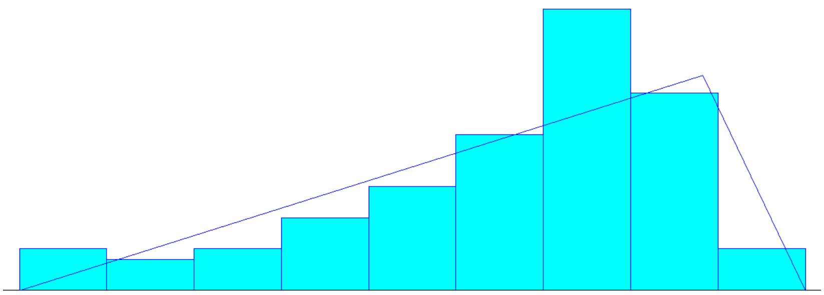


Figure 5.11 Passengers time spent on luggage claim area.

This process starts by carrying the items up to the conveyor belt and relies on both arrival of the luggage and arrival of the passengers to the conveyor belt. The time has a triangular distribution TRIA(5, 32, 36) as shown in Table 5.10.

Table 5.10 Passengers time from the jet way to vaccine and immigration stations

Distribution:	**Triangular**
Expression:	TRIA(5, 32, 36)
Square Error:	0.016598
Chi Square Test	
Number of intervals	5
Degrees of freedom	3
Test Statistic	7.52
Corresponding p-value	0.0594
Kolmogorov-Smirnov Test	
Test Statistic	0.088
Corresponding p-value	> 0.15
Data Summary	
Number of Data Points	93
Min Data Value	5
Max Data Value	36
Sample Mean	24.3
Sample Std Dev	6.9
Histogram Summary	
Histogram Range	= 5 to 36
Number of Intervals	9

The time taken to deliver luggage from the plane to the conveyor belt is revealed in Figure 5.12; it has been analysed by Arena input analyser and the best fit was Lognormal.

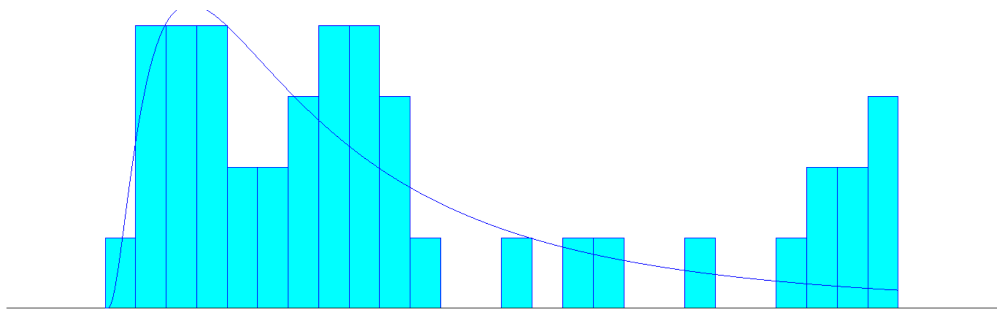


Figure 5.12 Time for delivering luggage from the plane to the conveyor belt

The distribution of that expression is 5.5 + ln(10.5, 12.6) with a sample mean of 15.3 and standard deviation of 8.04. Timing is found in detail in Table 5.11.

Table 5.11 Time for delivering luggage from the plan to conveyor belt

Distribution Summary	
Distribution:	Lognormal
Expression:	5.5 + LOGN(10.5, 12.6)
Square Error:	0.016580
Chi Square Test	
Number of intervals	= 6
Degrees of freedom	= 3
Test Statistic	= 10.3
Corresponding p-value	= 0.0181
Data Summary	
Number of Data Points	= 44
Min Data Value	= 6
Max Data Value	= 31
Sample Mean	= 15.3
Sample Std Dev	= 8.04
Histogram Summary	
Histogram Range	= 5.5 to 31.5
Number of Intervals	= 26

Analysis of this data led to the creation of a simulation model for the proposed system as described in Section 5.6 “Flowchart Modules Description”, to imitate and mimic the live scenario of the airport terminal then facilitate creating series of trials in groups to prepare regression and fuzzy logic analyses.

5.6 Flowchart Modules Description

A desecrate-event simulation model was produced to simulate passenger flow process with 710 modules in Rockwell Arena Software as shown in Table 5.12. The simulation model consists of 18 blocks (see Figure 5.13), which demonstrate the actual practised process in the Hajj terminal of King Abdul-Aziz International Airport. Firstly, the created entities in the model are arrival flights, those flights are created following the distribution that was gathered during data collection previously, according to the flight schedules. The data was transformed into an expression by the input analyser and changed to be arrivals per hour.

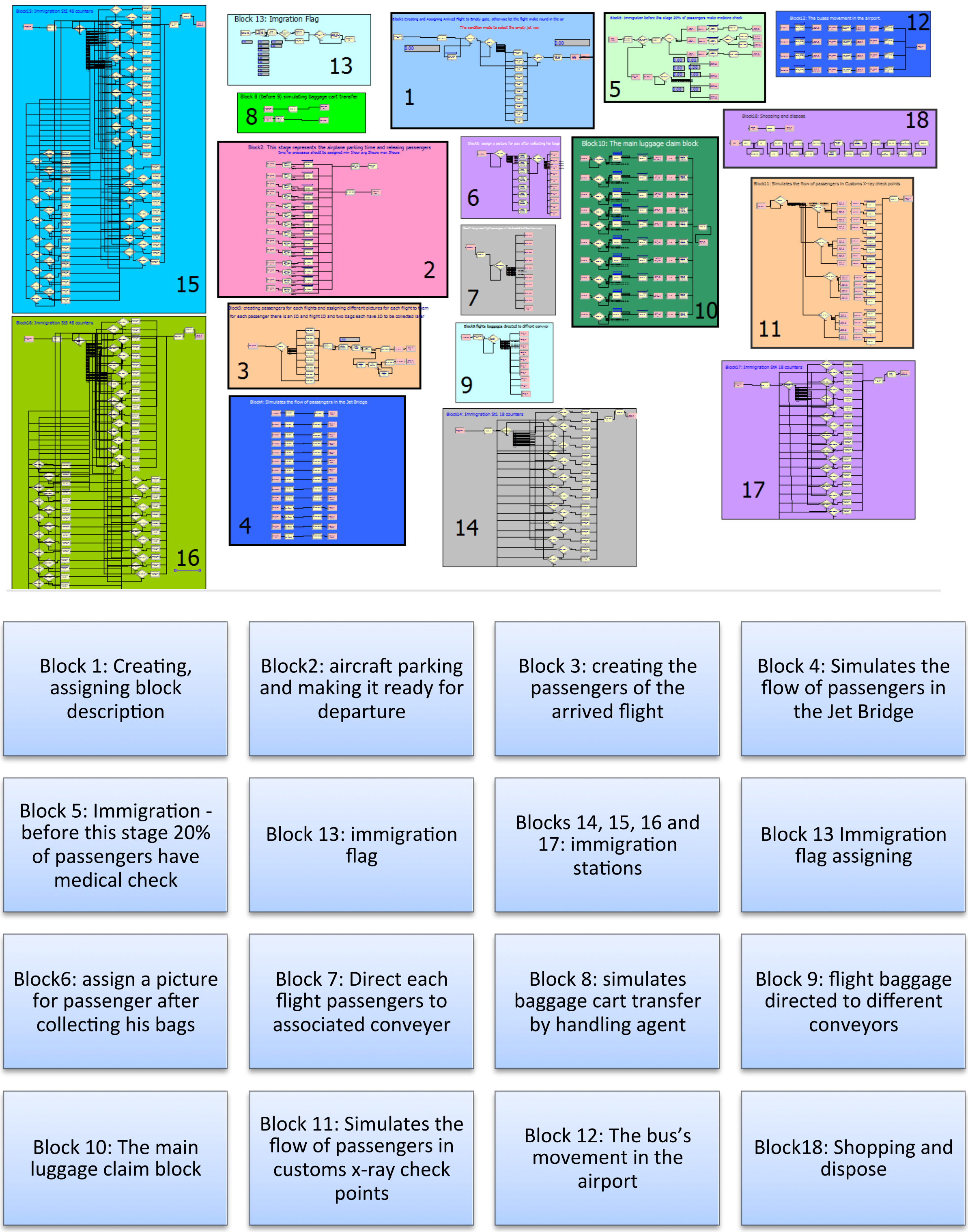


Figure 5.13 proposed logic design consists of 18 blocks

Secondly, the created flight is assigned to a free jet way, to allow the passengers and the luggage to be released to the terminal. This can take from one hour to a maximum of three, following the distribution generated from the input analyser as parking mode, when the plane occupies the jet way even after releasing the flight passengers - this will be clarified later in

Block 2. Some of the passengers are released by buses, as is seen in Block 11. Every released passenger as a simulation entity is tagged with an ID, which is related to the flight ID; every created flight in the model is tagged with its own ID. Even baggage entities hold these IDs in addition to the individual baggage ID; this allows passengers to collect their own luggage (only) from the conveyor belt. Station and Route modules are used in this simulation model to allow animation in the model and tracing during execution. For the sake of the animation, each passenger from a certain flight needs to have a different picture (with different colour) to allow distinguishing between passengers how have the same flight as illustrated in Block 3. Block 5 leads to immigration after passing the vaccine and health check point for some of the passengers (due to Ministry of Health regulations as mentioned previously), while others are released directly to immigration officers. The checked travellers go to the luggage claim area where they collect their baggage; this practice is done by "batch" and "match" modules which rely on Bag ID, Passenger ID and Flight ID appointed previously in the simulation model (Blocks 7, 8 and 9). Four customs stations are situated in the airport terminal, each station includes four x-ray machines to check and scan if there are any illegal or explosive items - this is illustrated in Block 10. Finally, passengers complete the process and are directed to the shopping and disposal station located in Block 18, which allow entities to exit the system.

Table 5.12 simulation model blocks

Name	No. of modules	Name	No. of modules
Block 01	19 (24 buses)	Block 10	72
Block 02	46	Block 11	56
Block 03	23	Block 12	33
Block 04	56	Block 13	9
Block 05	30	Block 14	42
Block 06	21	Block 15	102
Block 07	13	Block 16	102
Block 08	6	Block 17	42
Block 09	13	Block 18	25
Total No. of modules :		**710**	

5.7 Block 1: Creating, assigning block description

The first block, "Block 1" consists of 24 for the bus-activated model (19 when utilizing the jet ways to achieve better performance). As illustrated in Figure 5.14**Error! Reference source not found.** and Figure 5.14 this block starts with "create module" that generates entities of arrived flights following the mathematical expression that is made out of the analysed arrival flight data, as explained earlier.

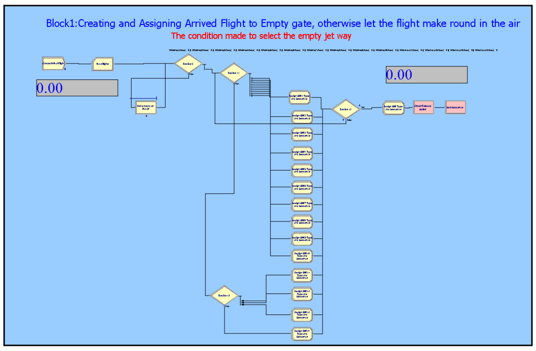


Figure 5.14 logic flow design chart.

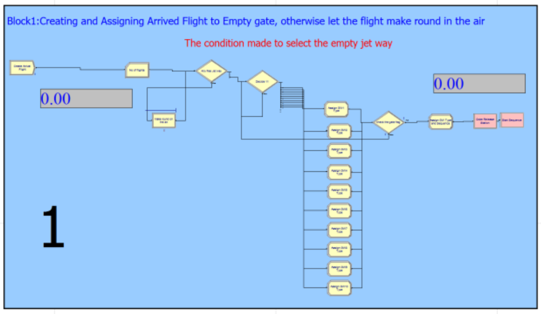


Figure 5.15 logic flow design chart after removing buses from the model.

That entity type is assigned to be the "Flight", as shown in Figure 5.16. The expression of the time between the arrival is classified to be Beta distribution function of (24/(29 + 232 x BETA(0.477, 0.576)) for year 2008 and 24/(TRIA(5, 53.3, 249)) for year 2013). Entities per arrival are adjusted to be one. (see Table 5.2 and 5.3).

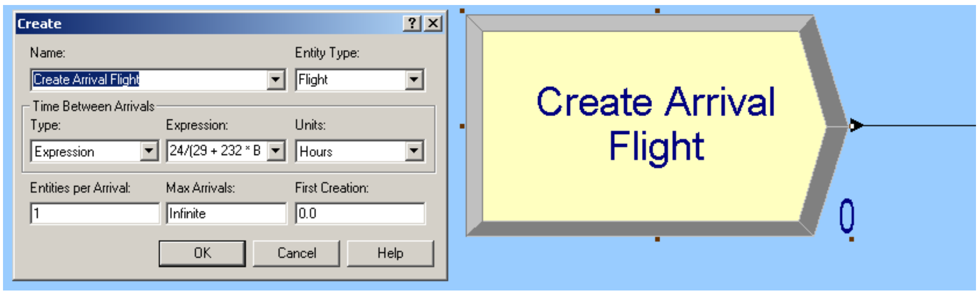


Figure 5.16 Block 1 - create module.

The number of flights is the crucial figure that can specify how many flights are being handled per hour or each day. This is considered to be measured by PPMDC as they aim to attain handling 10 flights per hour. This brings up the importance of counting and recording; this is done in the model by using record module of "count" type, with a value of "1" and the name "No of flights" as shown in Figure 5.17.

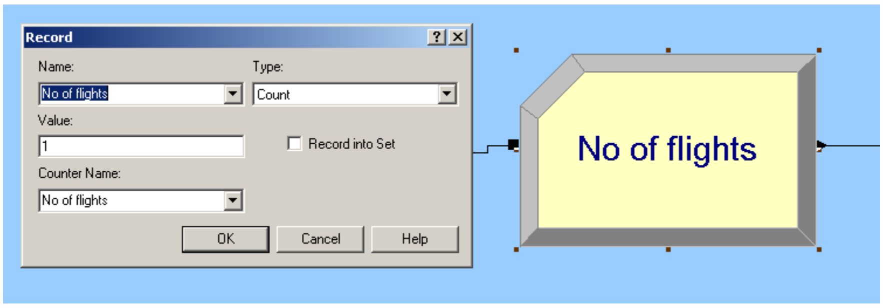


Figure 5.17 Block 1 – flight counting record module.

This is connected to the decision module (in Figure 5.18) that examines whether one or more jet ways are available (not occupied by any plane at this moment) and will use the first found free jet way in the airport terminal to release the flight passengers and luggage after assigning a parking mode, otherwise it will set a 5 min waiting period for the flight, as experienced clearly with airports that have a high level of traffic and limited resources like runways, such as at London Heathrow at peak times. This decision module has type of "N-way by condition" and the condition is set to be an expression which can check the jet ways and process queues. The airplane will then be seized for a time of one to three hours as is assigned by the airport authority; in the case of a certain plane exceeding that time, the airline company will be requested to move the airplane by the authority of the airport. The condition used is:

NQ(Jetway1.Queue) ==0 || NQ(Jetway2.Queue) ==0 || NQ(Jetway3.Queue) ==0 || NQ(Jetway4.Queue) ==0 || NQ(Jetway5.Queue) ==0 || NQ(Jetway6.Queue) ==0 || NQ(Jetway7.Queue) ==0 || NQ(Jetway8.Queue) ==0 || NQ(Jetway9.Queue) ==0 || NQ(Jetway10.Queue) ==0 || NQ(entrance11.Queue) ==0 || NQ(entrance12.Queue) ==0 || NQ(entrance13.Queue) ==0 || NQ(entrance14.Queue) ==0.

...... equation(4.1)

(The entances 11 to 14 are used for bus transportation mode, and can be ignored when only jet ways are used)

This condition is illustrated in Figure 5.18 as an input in the condition module with ends connected to jet ways and bus transfer stations.

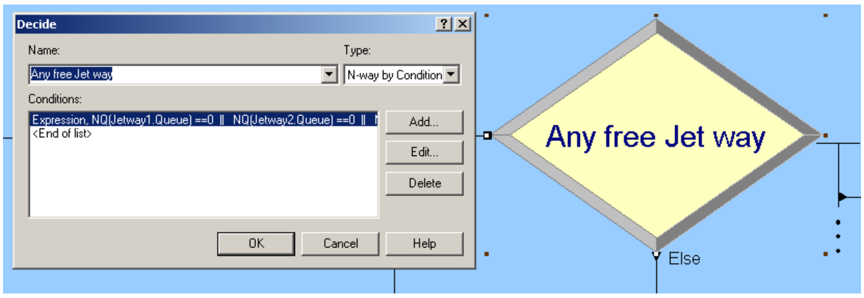


Figure 5.18 Block 1 - decide module

The decision module is used to assign a primary gate (at random) from the ten jet ways (and four additional if buses are used) that will still guarantee using the initial assigned gate as will be checked later (see Figure 5.19).

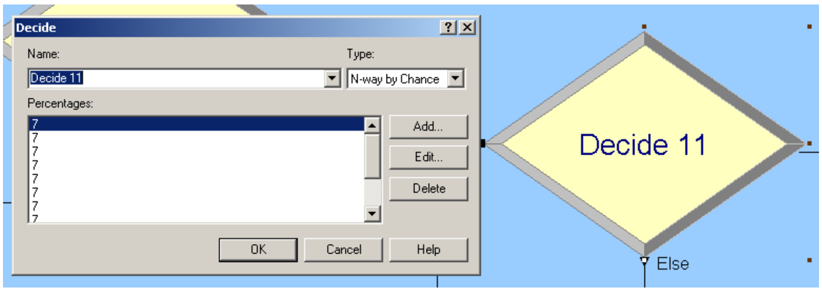


Figure 5.19 Block 1 - decide module.

An assign module is used to appoint attributes to each flight that allocates a jet way gate named "GW index". For example, jet way one has a value of 1, jet way two has a value of 2 and so on (see Figure 5.20).

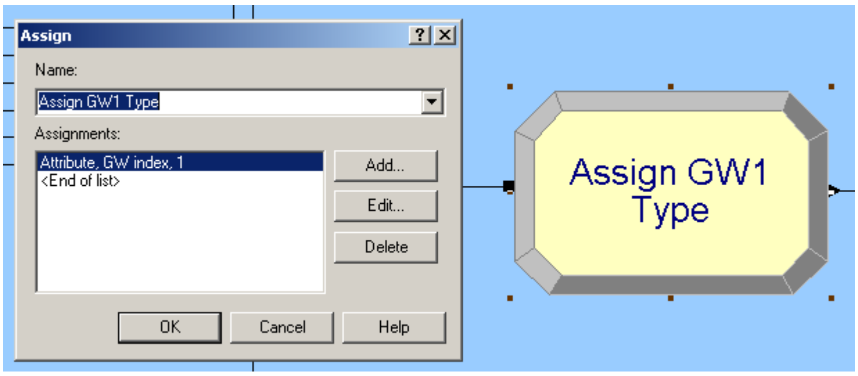


Figure 5.20 Block 1 - assign "GW1 Type" module.

Before parking the plane and releasing passengers at the initially selected gate, the state of that gate should be verified: whether the gate or the jet way is free or not and this can be known by the use of a "global array variable" which uses a flag to specify the state of the gate and decide if the gate is free or not; therefore, the value of the variable is equal to 0 if the gate is free and the value is 1 if it is occupied. The condition expression has been written in the decision module with a type of "2-way condition", as can be seen in Figure 5.21.

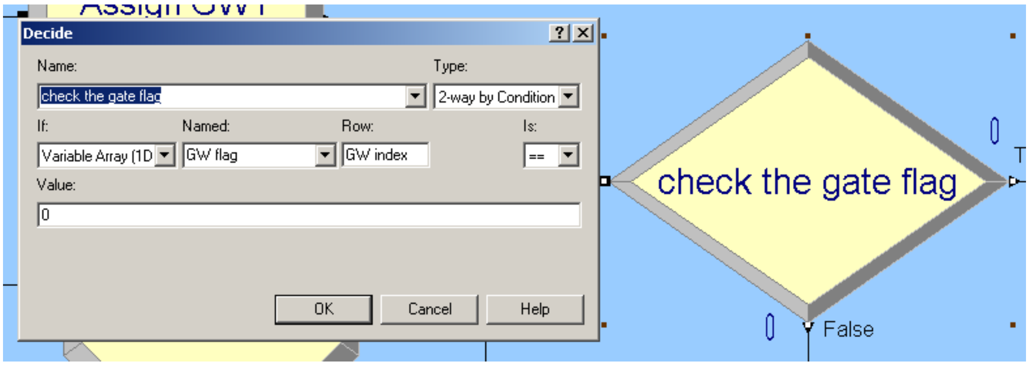


Figure 5.21 Block 1 - check the gate status module.

As soon as it is determined that the jet way gate is free, the flag will be set to "1" or occupied as classified earlier. The flight counter gained from the earlier record module is another attached variable as an attribute that has an initial value of 0 and is increased by increments of 1 each time a flight goes through the "assign module" and that will be used as the flight number which will distinguish between flights; also, this can be used afterwards to recognise many things like luggage of single flight to make sure it is delivered to a single conveyor belt, as it is usually done in airport terminals worldwide. The value of that counter will be tagged onto the entity with an attribute named "flight index". Then, this module will connect the appropriate "sequence" as an attached attribute that is used to route the entity throughout the map of model between sequences of stations, as shown in Figure 5.22.

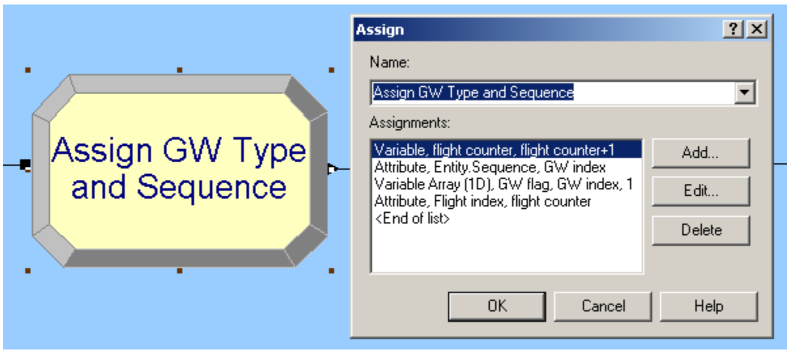


Figure 5.22 Block 1 - assign flight attributes and variables module.

'Order release station' comes after that assign module, and will route the "flight" entity through its way between stations according to the sequence that is attached as an attribute to the entity itself as shown in Figure 5.23.

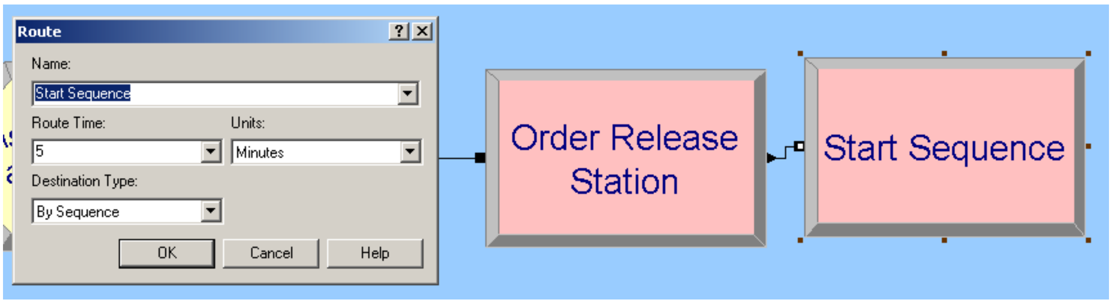


Figure 5.23 Block 1 - order release station flowed by route by sequence.

Fourteen sequences are created, ten of them guide the entities through their jet way gates e.g. "GW Station 1" sequence guides planes to jet way no 1, as illustrated in Figure 5.24.

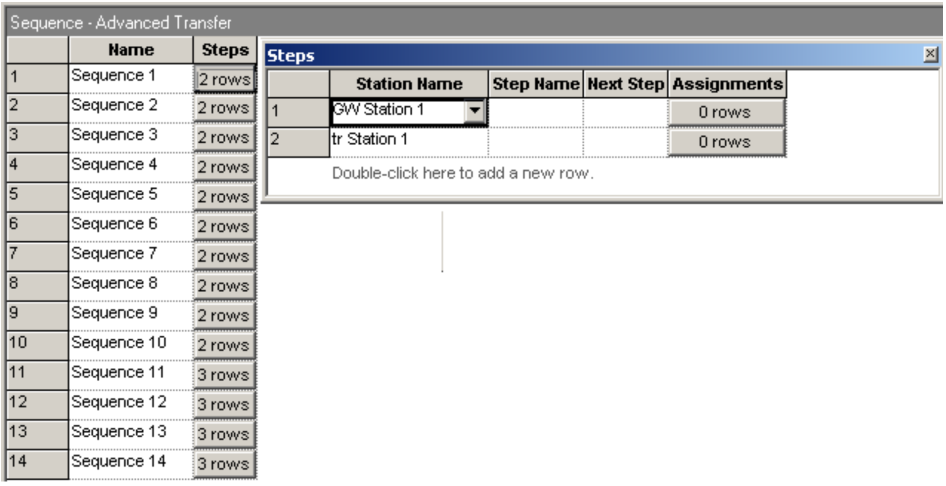


Figure 5.24 Block 1 sequences that identify the path of each gate index.

On the other hand, the other four sequences from 11 to 14 are different from the last ten since they dispatch "flight" entities to a parking area and after that call for buses to carry the arrived plane passengers, which is explained in Block 11; that can be seen in the bus movements in the airport as "Bus filling st 1", as shown in Figure 5.25.

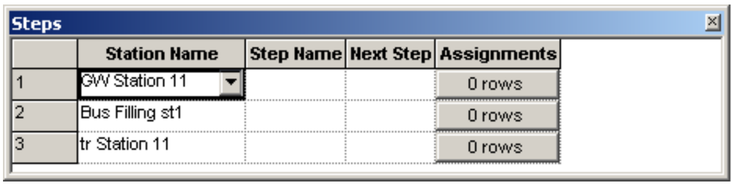


Figure 5.25 Block 1 - sequence that identifies bus movements.

5.8 Block2: aircraft parking and making it ready for departure

Normally, the arrived airplane has to spend sufficient time to prepare for another flight while it is in parking mode, and that mode makes the jet way appear to be occupied or used until its passengers are released and the plane is fuelled and catering supplies are replenished. That will seize the aircraft from one to three hours to be equipped and cleaned for the returning flight by changing the crew, fuelling the plane, and transferring the luggage to the baggage claim area in the terminal.

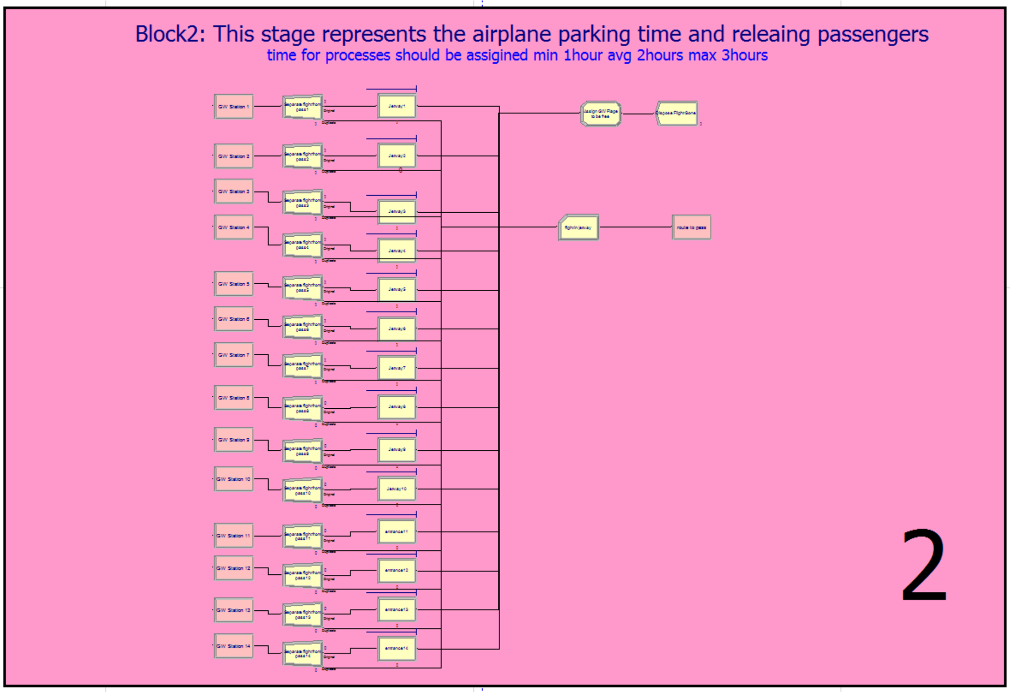


Figure 5.26 Block 2 - aircraft parking and making it ready for departure.

Block 2 logic structure contains 46 modules as is illustrated in Figure 5.26. The main concept in this logic is to duplicate the "flight" entity by a separate module and then seize the original entity to be in the parking mode as it is occupying the jet way by a single resourced process with "seize delay release" type with a triangular distribution of three values, as shown in Figure 5.27.

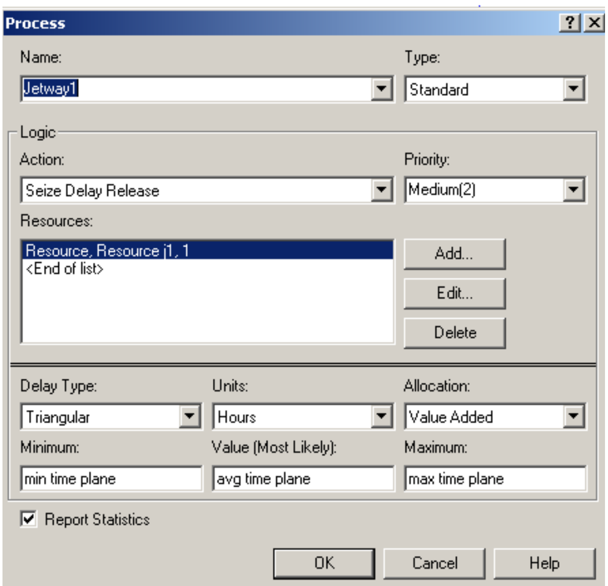


Figure 5.27 Block 2 - "seize delay release" type process module.

The same concept is done to the rest of the jet ways and all are followed by an assign module which releases the plane and makes the jet way available for newly arrived aircraft by releasing the original flight entity to the assign module and setting the "GW flag" to zero which means free or available.

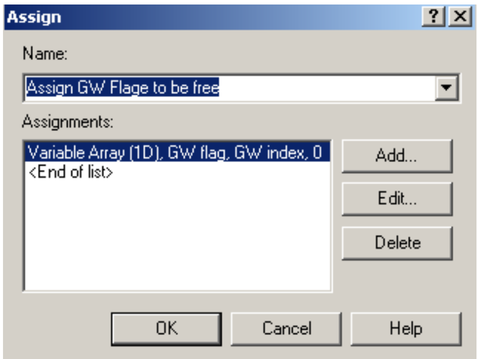


Figure 5.28 Block 2 - assign module.

Figure 5.28 shows how the jet way could be released after the process module, by making the flag index variable equal to the value of zero. Then the "flight" entity will be disposed by the dispose module, and the created duplication will directed to Block 3.

5.9 Block 3: creating passenger entities of an arrived flight

Enhancing the performance of passenger process flow management is the key purpose behind this research. Block 3 produces the passengers as entities based on gathered data from landed flights in the Hajj Terminal in 2013 and assigns their entity images with eight entity pictures to make it easy to differentiate between flight passengers. This block uses the data collected from the PPMDC and analysed earlier in the data section of this study. The block contains 24 modules and is illustrated in Figure 5.29.

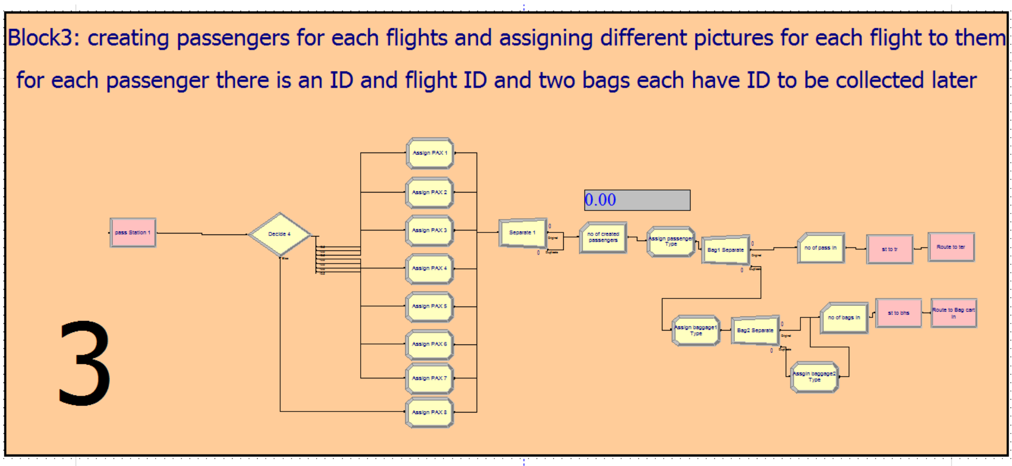


Figure 5.29 Block 3 - the logic model of creating the passengers of the arrived flight.

In the animation model, various nationalities are simulated by randomly assigning a different entity picture for each flight passenger (e.g. Nigerian flight passengers green and Turkish flights red) and that is done by a decision module of the "8-way by chance" type where it takes a flight entity then directs it to one of its ends. This is described in Figure 5.30, and each way has a chance of 12.5%.

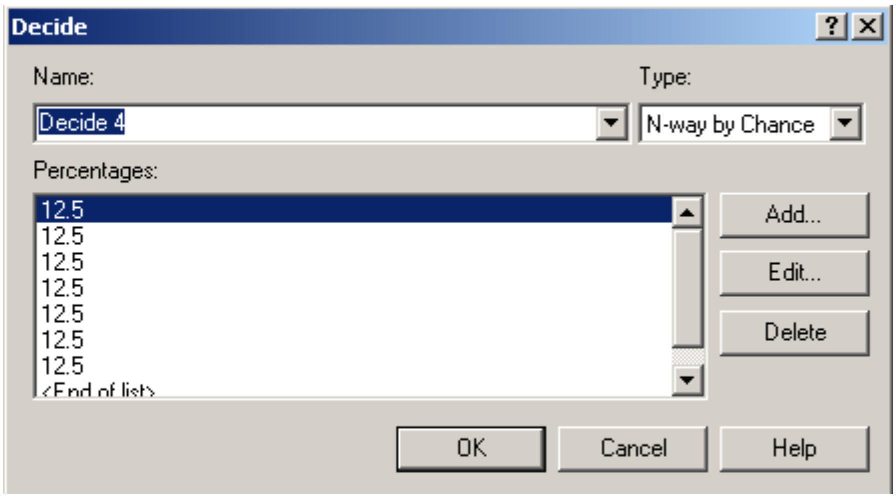


Figure 5.30 Block 3 - the 8-way by chance decision module.

Assigning the passenger type as an attribute and the picture as an attached picture is done by an assign module as is illustrated in Figure 5.31. The passenger type has been embedded in the entity as an attribute (passenger type an integer between 1 and 8) and the entity picture is allocated afterwards.

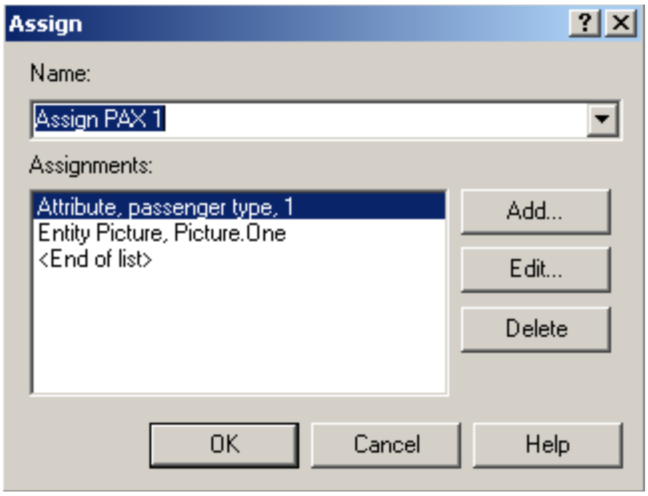


Figure 5.31 Block 3 - passenger type assign module.

Figure 5.32 demonstrates the pictures used in the previous assign module, including Picture.one, Picture.two, …, Picture.eight. The remaining pictures are used later for status classification like picture.onewb that specifies whether the passenger has collected his/her luggage or finished the baggage claim process; this will be discussed later.

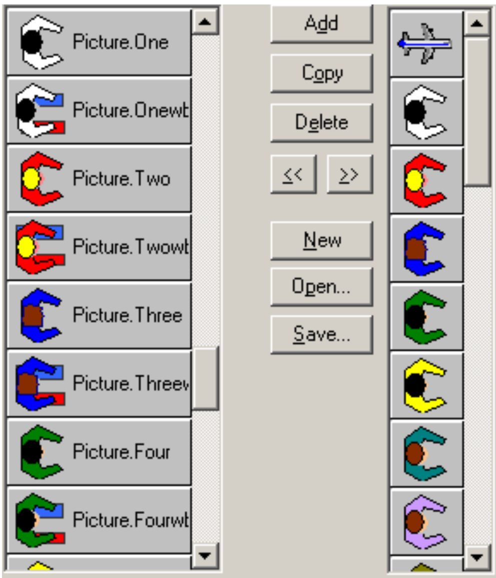


Figure 5.32 Block 3 - passenger type assign module.

Three separate modules are used in this block; beta distribution is used to simulate the number of passengers per flight (as analysed earlier in the input analyser). The number of duplicates equals “10 + 240 x BETA(1.27, 0.441)” and the type of separate is a duplicate of the original (see Figure 5.33).

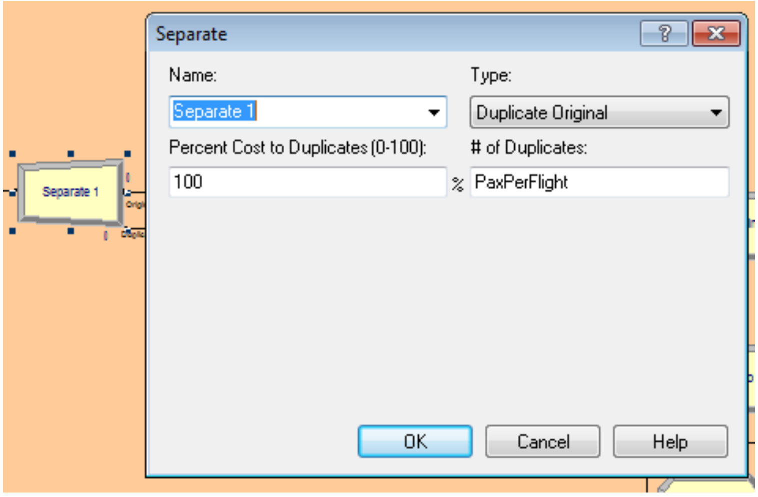


Figure 5.33 Block 3 - creating passenger duplication by a separate module.

The created entities from separate passengers are tagged each with an ID and other attributes to allow passengers to identify their baggage at the baggage claim area with an assign module with the following details. Firstly, an initial value of zero can be assigned to a global variable created and named “passenger counter”. Secondly, the assign module can include an increment on that variable value as “passenger counter = passenger counter + 1”. Thirdly, an attribute is created and called “passenger index” which can capture that counter value and tag it to each “passenger” entity - that “passenger index” attribute can be used as a unique ID for each passenger in that flight. Finally, the “entity type” should be assigned as “passenger” (see Figure 5.34).

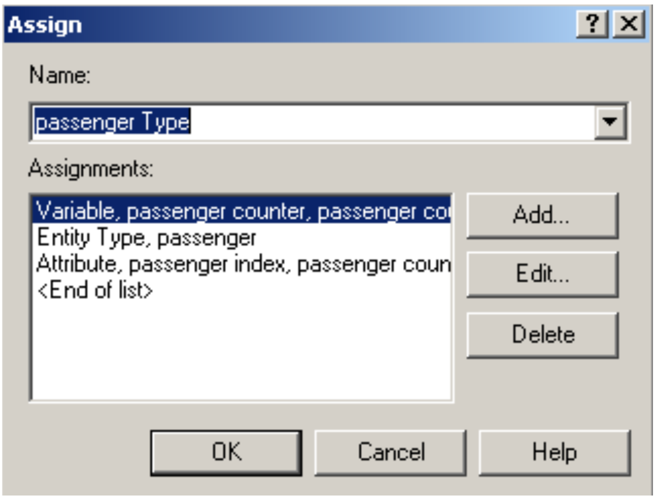


Figure 5.34 Block 3 - creating a passenger’s ID by separate module.

Each entity is created by a separate module as duplicates inherit all of the parent entity attributes, consequently “passenger index” is required to allow baggage owners to claim their specific baggage. Figure 5.35 shows the duplication of the first item of the passenger's baggage.

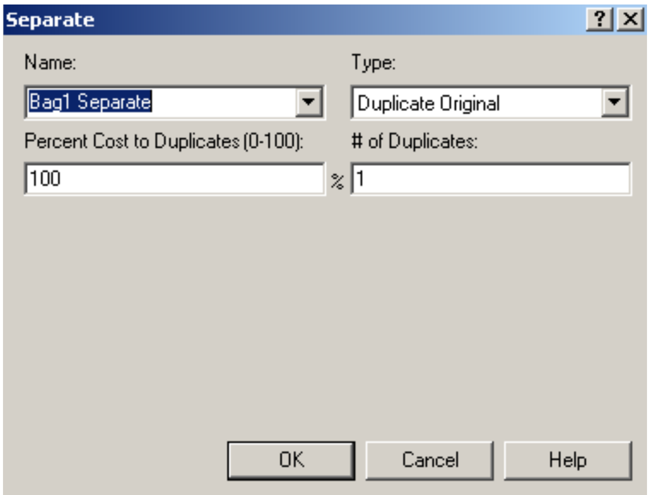


Figure 5.35 Block 3 - creating passengers' bags by separate module.

The entity type needs to be transformed from "passenger" type to "baggage" type and an additional attribute is added called "bag no". According to that "bag no", each "baggage" entity picture will be assigned; for instance, the first bag will be a blue coloured bag picture and the other one will be a red coloured bag picture (see Figure 5.36).

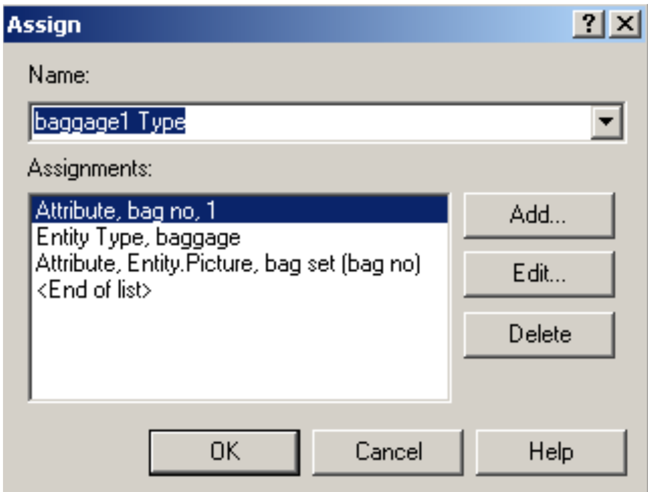


Figure 5.36 Block 3 - change the entity type to baggage by assign module.

Figure 5.37 illustrates the entity picture assigned to the bags as discussed. Moreover, a set called "bag set" contains these two pictures.

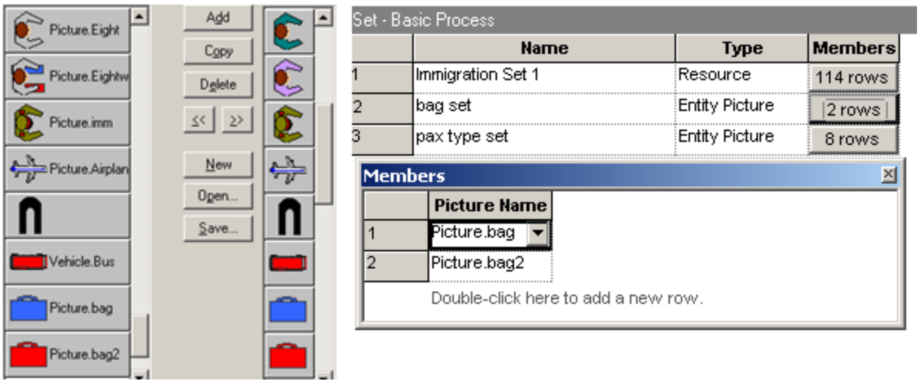


Figure 5.37 Block 3 - bag entity picture.

The second bag is created as a duplication of bag no 1 by a separate module (called "bag2 separate") by changing the value of "bag no" attribute to 2 (in an assign module called "Assign baggage 2 type"). This attribute will automatically change the second bag to red, as shown in Figure 5.38.

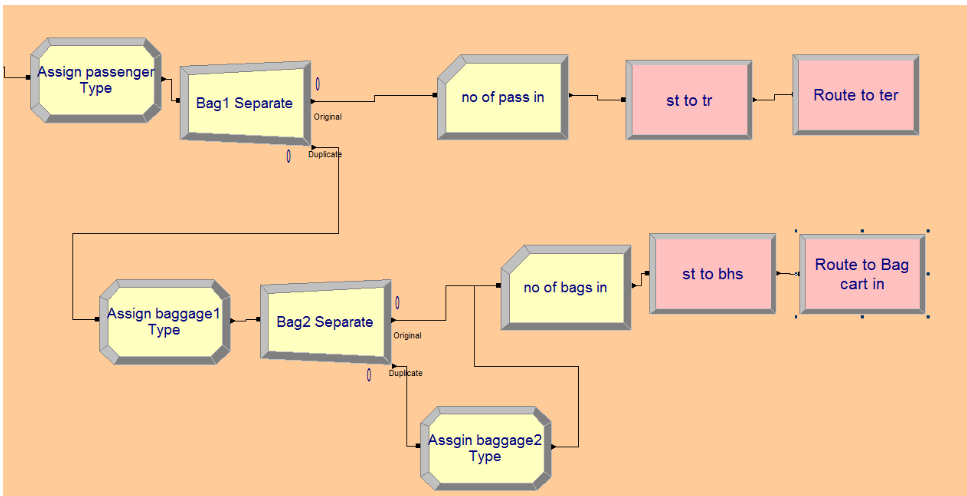


Figure 5.38 Part of the block 3 logic design.

For counting the total number of passengers and bags that entered the system, two record modules should be added. Passengers are sent to other terminal processes and the baggage is directed through the makeup area to the Baggage Handling System (BHS) mainly by transferring baggage carts at the end of the block by two route modules.

5.10 Block 4: Simulates the flow of passengers in the Jet Bridge

The simulation of the jet way (or the jet bridge) passengers' flow can be found in Block 4 with 65 modules. A station module enters entities to the block then those entities are delayed by using "delay" process modules which represent the walking time (see Figure 5.39).

Figure 5.39 Block 4 - the block logic design for the flow of passengers in the Jet Bridge.

Then, in order to count the number of "passenger" entities released, each entity will be directed through the record module to specify who has passed through each jet way. Finally in this block, a route module is added to direct passenger entities to health check points (medical vaccine point) or to Block 5 the immigration process block.

5.11 Block 5: Immigration - before this stage 20% of passengers have medical check

Passengers are directed to the health check vaccine points and passport check points as can be illustrated at Block 5. Coordination is required between the Ministry of Health and the airport operator to classify specific flights that should be checked and given vaccinations before the plane's arrival; this is determined from the detailed report that was spread internationally by the World Health Organisation (WHO), and it is predicted that this number accounts for 20% of the whole number of passengers who reach the Hajj terminal. Passengers are sent afterwards to the passport check points where their visas and passports are checked and their finger prints scanned by the passport department.

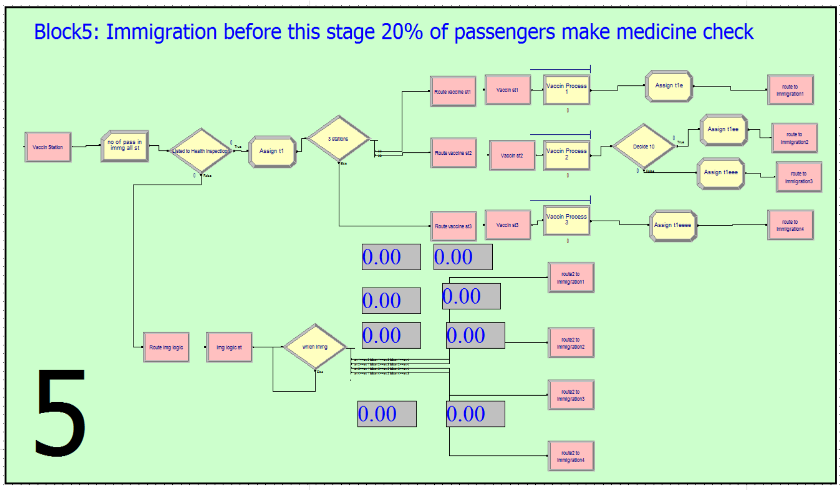


Figure 5.40 Block 5 the block logic design for the vaccine process and immigration passport control.

Block 5 is built using 30 modules (see Figure 5.40) and it begins with the station module connected to a record module (as a counter), in addition to the decision module named “Listed to Health inspection” with a 2-way by chance with a ratio true value of 20%, as shown in Figure 5.41.

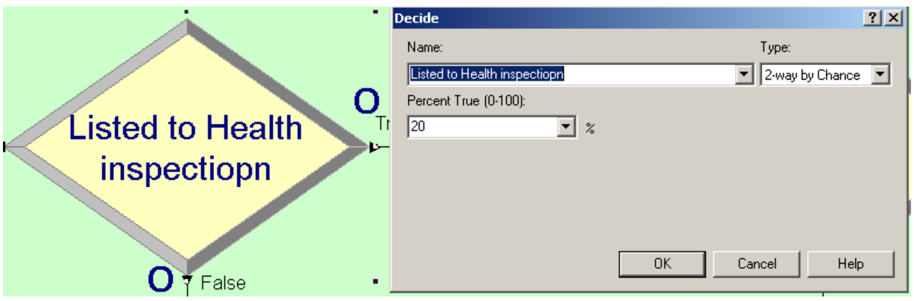


Figure 5.41 Decision module for listed countries for health inspection.

Then it is linked to a new decision module with an N-way by chance named “3 stations” from the “true” out end, which splits passengers between three assigned vaccine stations in the airport terminal (as shown in Figure 5.42).

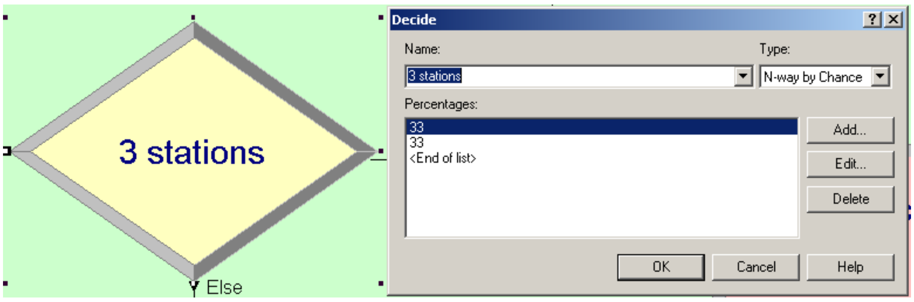


Figure 5.42 Decision module for dividing passengers into three stations.

The three ends are connected to three route modules, and route stations send entities to the three health check vaccine stations. The route modules are created with settings as illustrated in Figure 5.43.

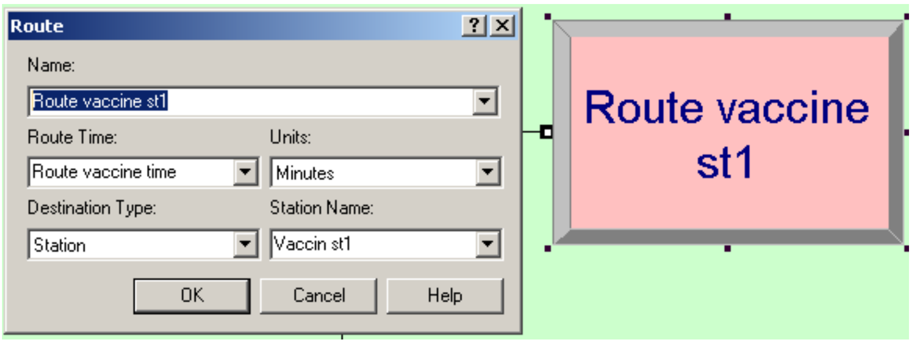


Figure 5.43 Route module that is used to route individuals to vaccine stations.

The other end of the decision module named "Listed to Health inspection" with "false" logic is attached to the decision module named "which immg" which is shown in Figure 5.44.

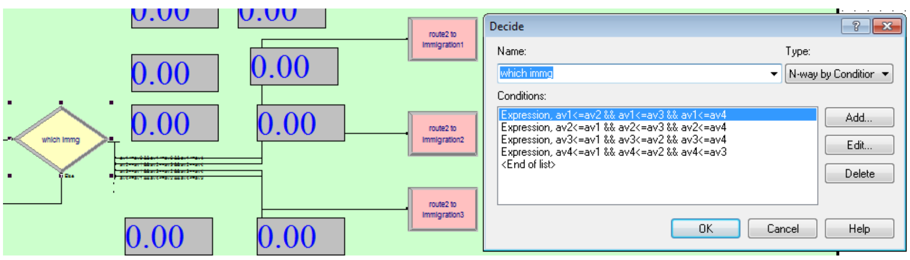


Figure 5.44 Decision module for dividing passengers between the four stations.

The "which immg" decision module will direct the remaining passenger entities by a "route" module shown in Figure 5.45 to the immigration stations (Blocks no 14, 15, 16 and 17) with a checking expression that finds which stations have a lower ratio of used points in that station, and that is affected by the number of immigration staff available in that shift or at a certain time; that is simulated in Block 13 and discussed later.

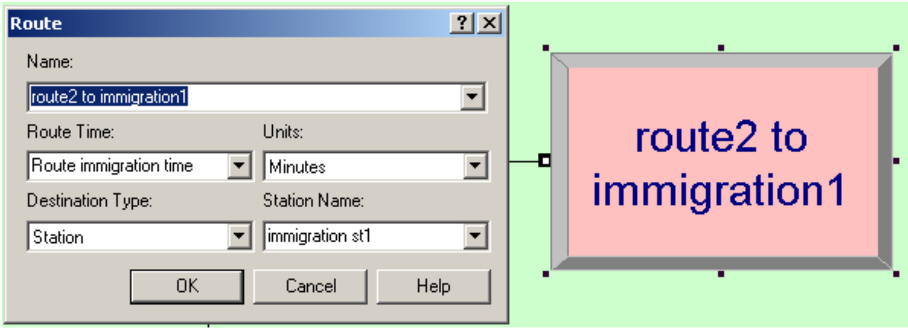


Figure 5.45 Route module that is used to route to the immigration stations.

The health check and vaccination logic can be illustrated in Figure 5.46, as entities will be directed to the process module with logic action type of "seize delay release" as shown in Figure 5.47 and sent afterwards to an immigration logic station in the same block to prepare it to be released to the immigration blocks no 14, 15, 16 and 17. An assign module is added to capture and record the time "tnow" as an attribute to the "passenger" entity so it will be helpful for studying and calculating some factors later.

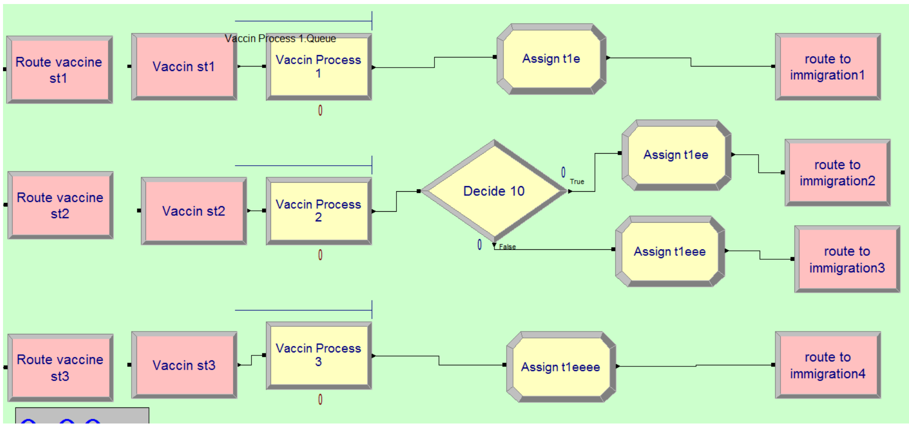


Figure 5.46 Vaccine stations logic chat of modules.

The process module named "Vaccine Process 1" with logic action type of "seize delay release" is illustrated in Figure 5.46 with "standard" type and a resource to allow modelling of capacity then an "assign" module is linked to it. The same applies to the other two stations; they have "Vaccine Process 2" and "Vaccine Process 3" process modules with the same configuration.

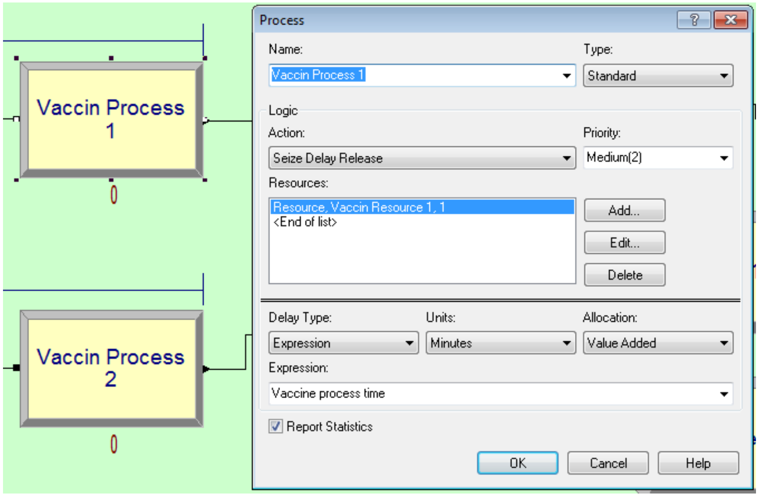


Figure 5.47 Vaccine process module configuration.

The “assign” module is linked to the end of the process and has the name “Assign t1e” with assignment of “t1e” attribute with the value of “tnow” as described in Figure 5.48.

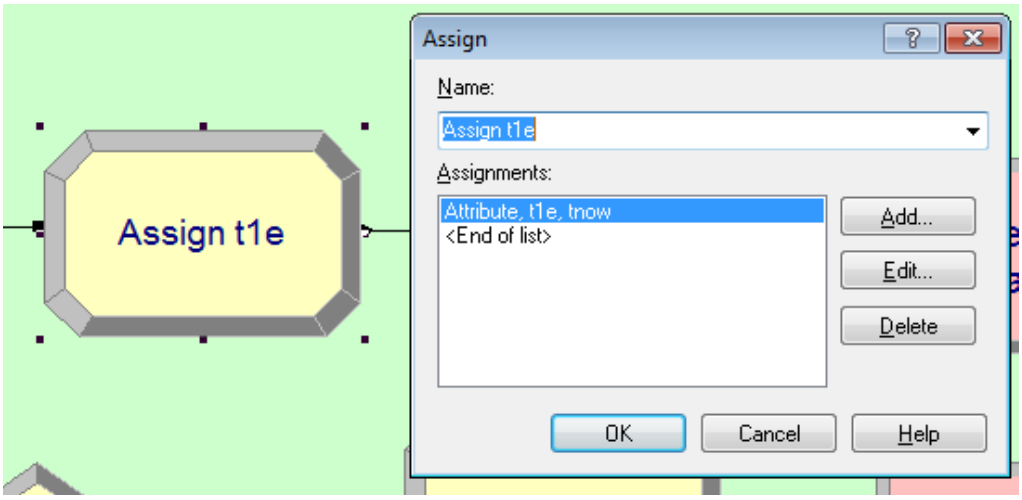


Figure 5.48 assign module

An assign module is added to capture and record the time “tnow” as an attribute to the “passenger” entity. Finally routing to the immigration station is done by a “route” module which has a “route immigration time” route time in minutes and destination type of “station” and station name “immigration st1”, “immigration st2”, “immigration st3” or “immigration st4” as they are located in Blocks no 14, 15, 16 and 17. Figure 5.49 shows these stations.

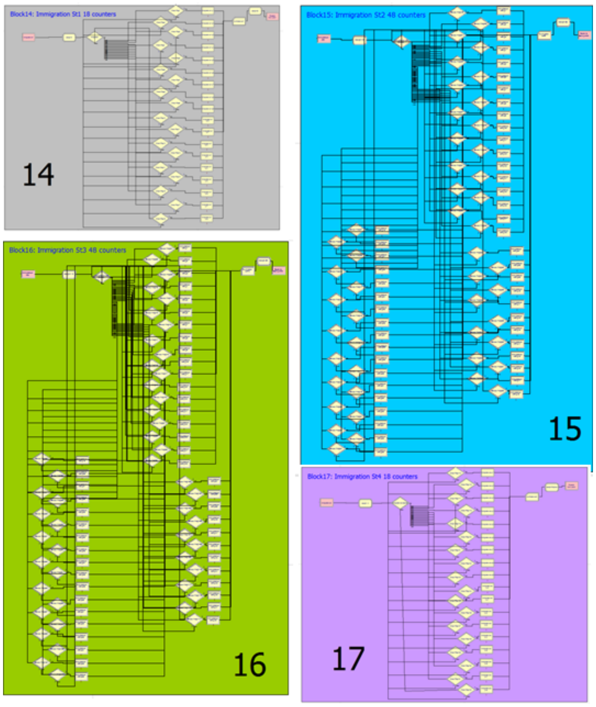


Figure 5.49 logic chart of blocks 14, 15, 16 and 17 representing immigration stations 1, 2, 3 and 4.

5.12 Block 13 immigration flag

The same can be applied in the immigration station which has been configured with the assumption that immigration points are not all utilised all the time.There is a block that allows to set the ratio of utilization for each shift or day or any assigned period which calculates the number of officers based on that ratio which is shown in Figure 5.50 of Block 13.

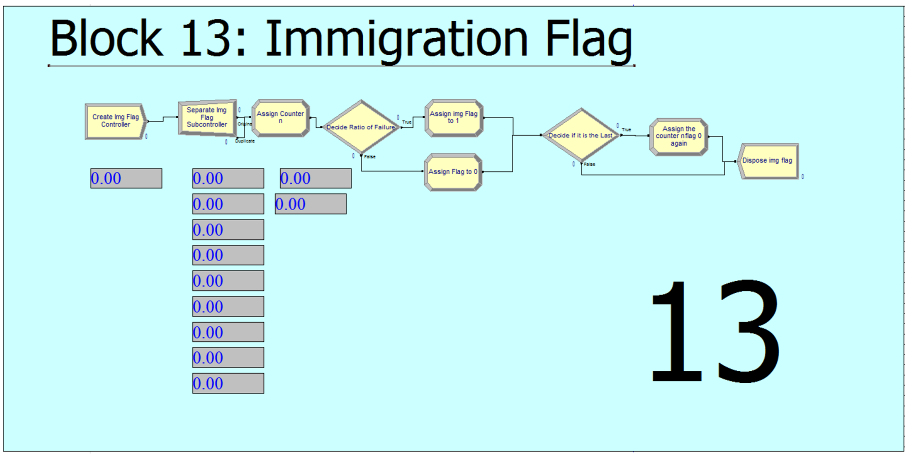


Figure 5.50 Logic chart of Block 13 immigration flag simulating ratio of available immigration officers.

This path is identified by four route stations as clarified earlier in Block 5 (see Figure 5.40, Figure 5.44, Figure 5.45 and Figure 5.46). Each route module has destination type "station".

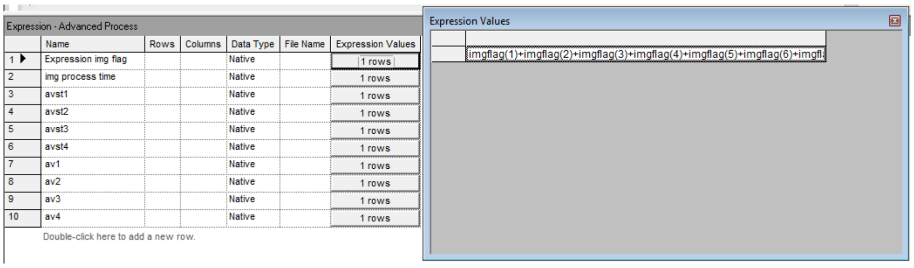


Figure 5.51 Expressions used to identify which immigration station the entity will directed to.

As shown in Figure 5.51 all expressions are exposed in detail as follows:

Expression img flag =

imgflag(1)+imgflag(2)+imgflag(3)+……+imgflag(131)+imgflag(132)

(counts how many points available in total)

...... equation(4.2)

The following counts how many points are available in each station

- avst1 =imgflag(1)+imgflag(2)+imgflag(3)+……+imgflag(18)
- avst2=imgflag(19)+imgflag(20)+imgflag(21)+……+imgflag(66)
- avst3=imgflag(67)+imgflag(68)+imgflag(69)+……+imgflag(114)
- avst4=imgflag(115)+imgflag(116)+imgflag(117)+….. +imgflag(132)

...... equation(4.3)

Ratio of how many work-in-process entities to the points available in each station

- av1=(Nimg1in-Nimg1out)/(avst1+1)
- av2=(Nimg2in-Nimg2out)/(avst2+1)
- av3=(Nimg3in-Nimg3out)/(avst3+1)
- av4=(Nimg4in-Nimg4out)/(avst4+1)

...... equation(4.4)

5.13 Blocks 14, 15, 16 and 17 immigration stations

As a passenger entity entered some flags have been already configured assuming some points which are simulated as resourced "size-delay-release" process modules are out of service as they are not staffed. For that reason a decision module can be used to check the flag prior sending an entity to a certain point as it is explained in this section.

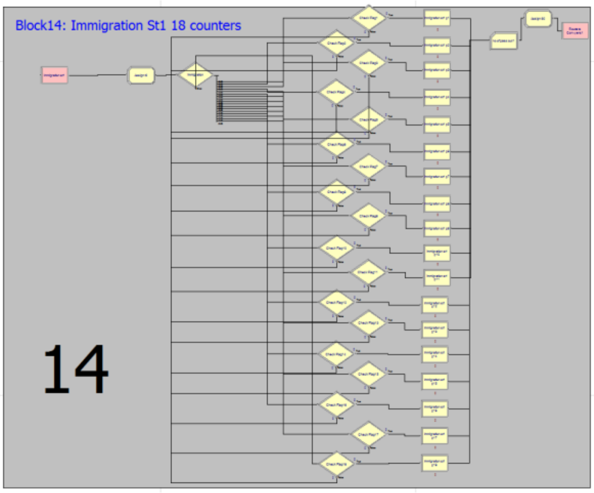


Figure 5.52 logic chart of block 14 immigration station.

Block 14 contains 45 modules 18 "process", modules, 19 "decide" modules, 2 "assign" modules, a "record" module, a "station" module and a "route" module as illustrated in Figure 5.52.

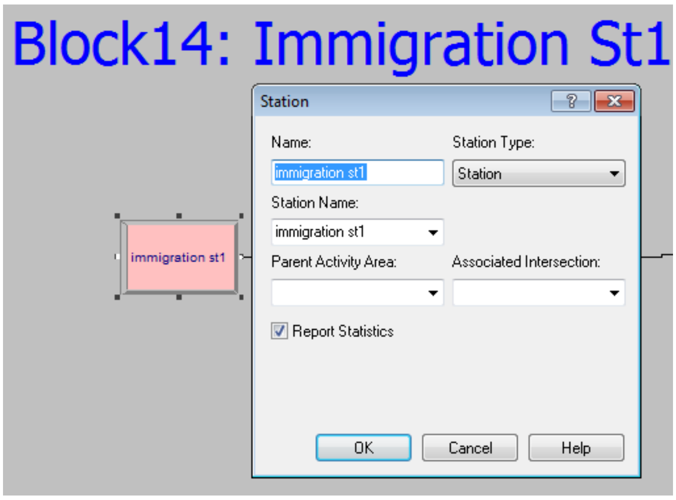


Figure 5.53 station module named "immigration st1".

Firstly, the station module named “immigration st1” is created to receive routed entities from Block 5 with station type “station” as is illustrated in Figure 5.53.

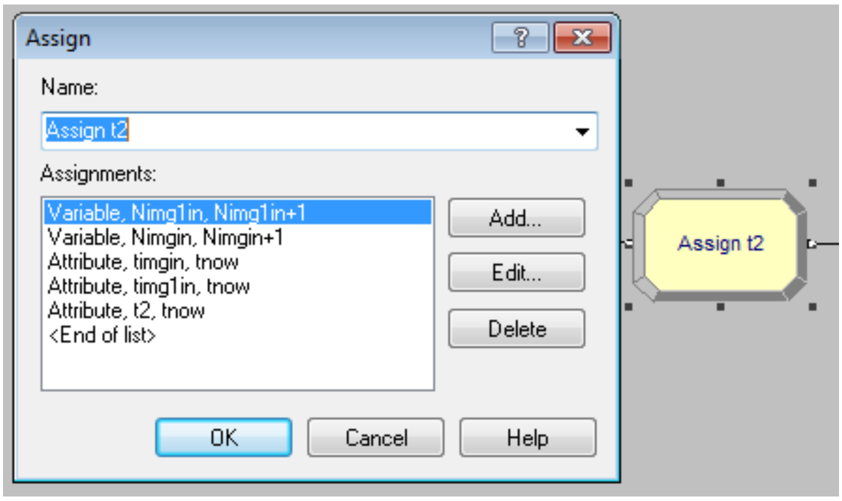


Figure 5.54 assign module named “Assign t2”.

Then, an “assign” module is created to set some variables and attributes used to identify which block is busiest (from blocks 14, 15, 16 and 17) to avoid sending passengers to such block. Others are used meanwhile to capture and record the time of entities, as this data can be used later as output data. This assign module sets all required figures related to entered entities, while there is another one used later which sets all required figures related to leaving entities. “Nimg1in” is a global variable associated to immigration station 1 or (Block 14) as a counter initiated with zero value and increased by entities passing through it with an increment of one. On the other hand, “Nimgin” refers to all stations and can tell you how many passengers entered all immigration stations at any certain time. In addition, “timg1in” and “t2” capture the time of entering the station as shown in Figure 5.54.

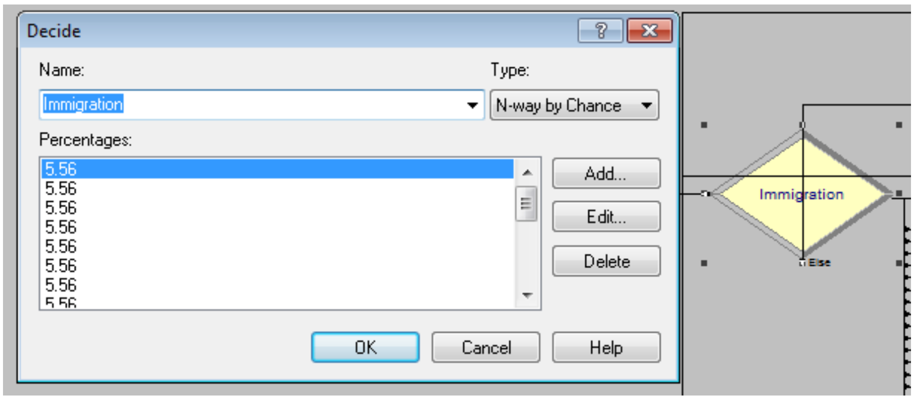


Figure 5.55 decision module named "immigration".

After that a decision module is used to distribute entities with equal ratio (or chance) to all immigration points. The decision module named "immigration" is "N-way by chance" type and the percentages are equal to 5.56 as there are 18 immigration points, as shown in Figure 5.55.

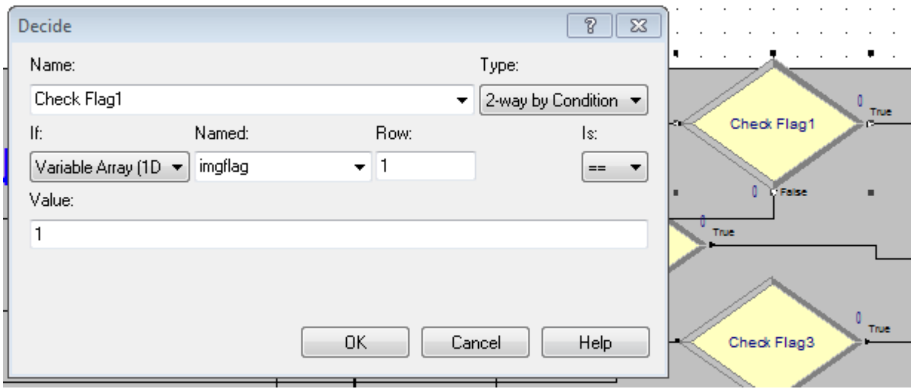


Figure 5.56 decision module name "Check Flag1".

In this decision module the state of the immigration point is checked with "imgflag" variable: if it equals one that means the immigration point has an officer, otherwise it means the point can be used. True logic is connected to the process module while the false logic is connected back to the first decision module named "immigration" as shown in Figure 5.56.

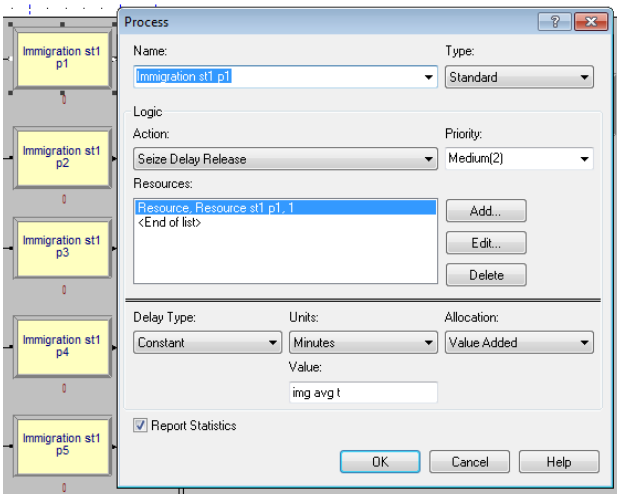


Figure 5.57 Process module "immigration st1 p1".

As mentioned, the immigration point is considered as a resourced process module in this process flow as it has type "standard" and logic action of "seize delay release" as shown in Figure 5.57.

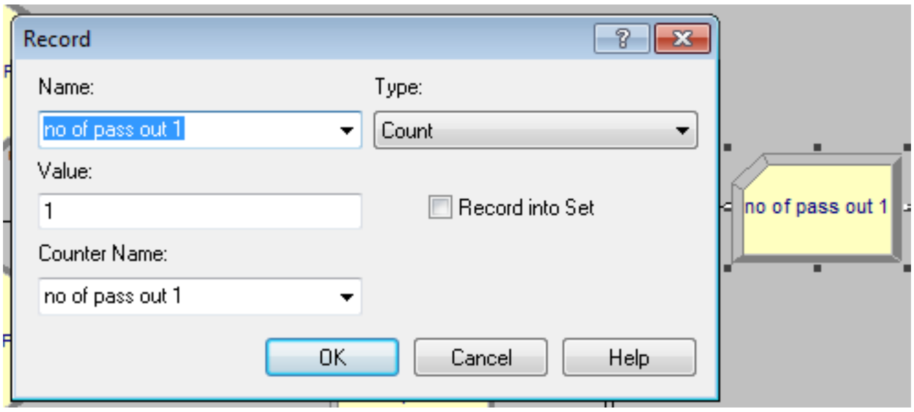


Figure 5.58 record module named "no of pass out 1".

Then a record module is used to count the number of leaving entities which can tell us the number of checked passengers for that specific block as shown in Figure 5.58.

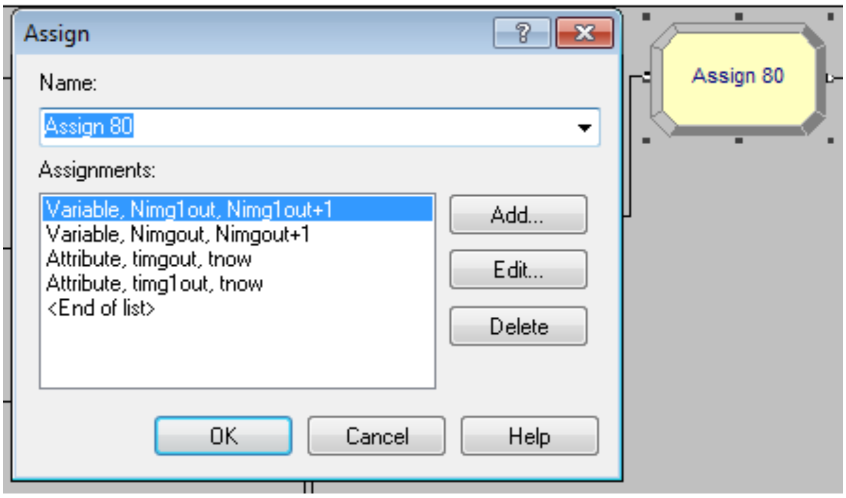


Figure 5.59 assign module named "Assign 80".

This assign module sets all required figures related to leaving entities as mentioned earlier in the first assign module. The "Nimg1out" global variable is associated to immigration station 1 or (Block 14) as a counter initiated with zero value and increased by passing entities through it with increments of one. On the other hand, "Nimgout" refers to all stations, and can tell you how many passengers leave all the immigration stations at any certain time. In addition, "timg1out" captures the time of leaving the station as shown in Figure 5.59.

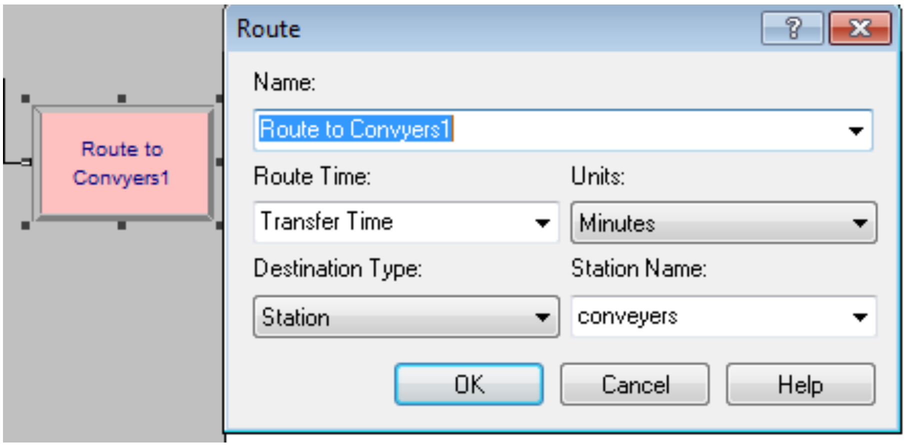


Figure 5.60 route module named "Route to convyers1"

This route module directs entities to conveyor belts to collect their luggage in Block 7. The route time is configured to be "Transfer Time" and the destination type set to be "Station" and the station name is "conveyers" as shown in Figure 5.60.

5.14 Block 13 Immigration flag assigning

This block is created as a controller block which assumes and decides how many and which immigration counters or points are active and which are not. That can be done based on the ratio of the assigned number of available immigration staff in the airport at any specific time (see Figure 5.61). This block is created on the logic of creating a controller entity, then duplicating it with the number of total immigration points in the whole airport. Then, those entities are divided between two paths by the assigned ratio as a chance percentage. The first path assigns a flag with the value of one (assumed to be active) while the other assigns a flag with the value of zero (assumed to be not active).

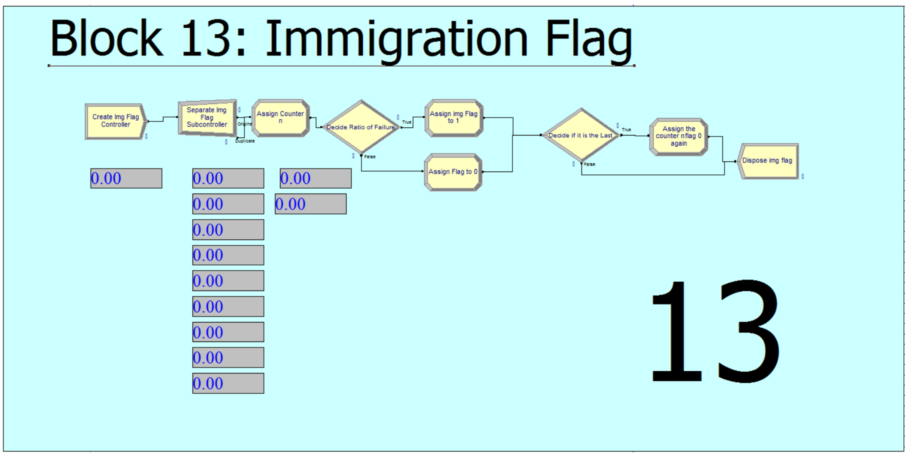


Figure 5.61 logic chart of block 13 with its modules

Firstly, a create module is used to create an entity named ”Create Img Flag Controller” with entity type of “Entity Flag controller”. This value is set at 1, the units set as “Days” and entity of arrival is 1 with max of 1. This can be changed to do different ratios for each shift (e.g. 8 hours) or any other period based on the actual practice in the terminal (see Figure 5.62).

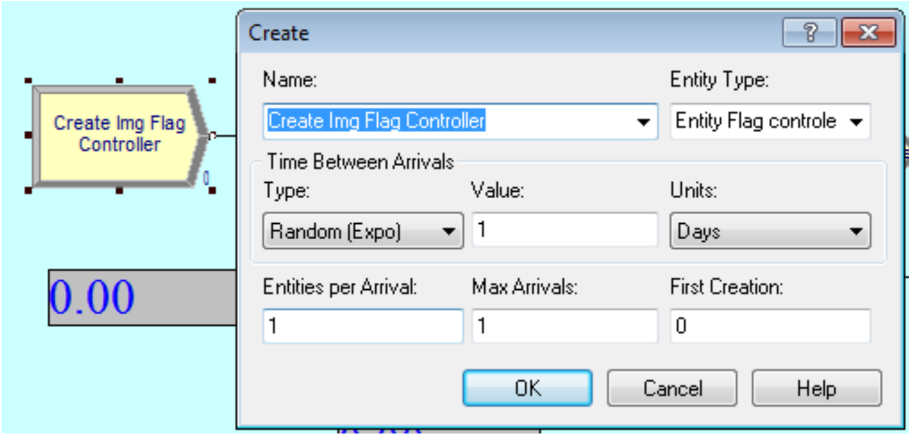


Figure 5.62 "create" module for initiating immigration flag controller entity.

Then, a separate module can be attached to create subcontrollers. The name is assigned to be "Seprate Img Flag Subcontroller" with the type of "Duplicate Original" and the number of duplicates equals 132 which represents the number of immigration counters as shown in Figure 5.63.

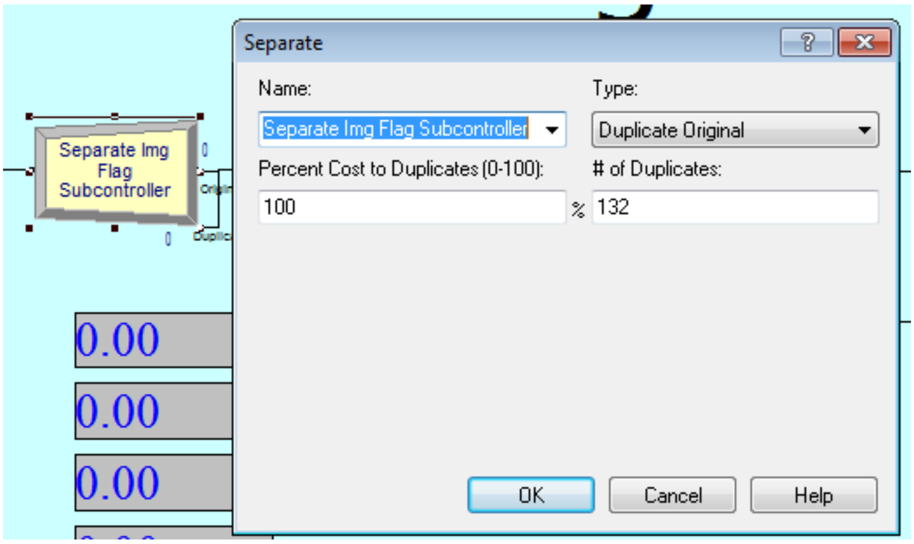


Figure 5.63 separate module controller to create subcontrollers

That is followed by an assign module called "Assign Counter n" which updates a global variable value named "nflag" with increments of one. This will be used to identify the flag number as seen in Figure 5.64.

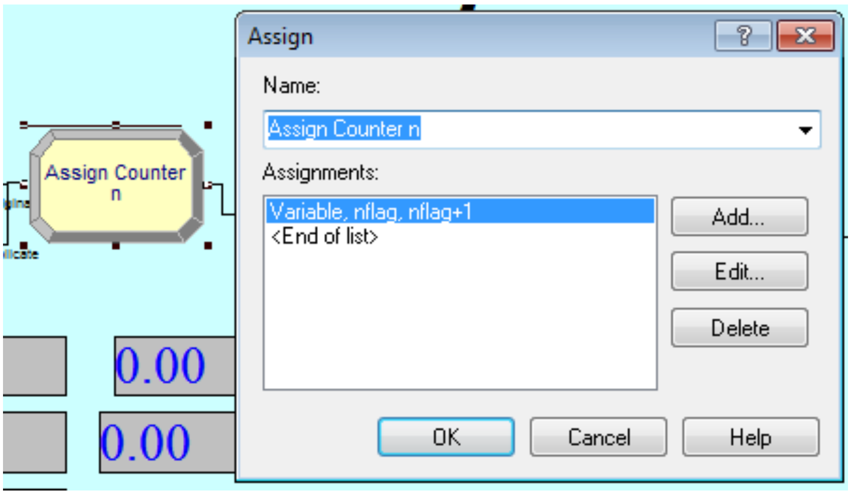


Figure 5.64 assign module to count number of flags

A decision module named "Decide ratio of failure" is linked to simulate the ratio of active immigration points in the terminal. The type is set to be 2-way by chance and the percentage equals the variable "PercentAvImg" as shown in Figure 5.65.

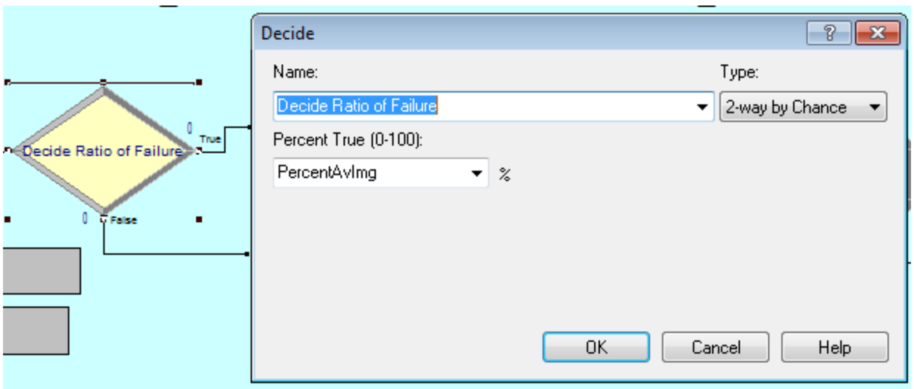


Figure 5.65 decision module that converts the ratio of availability to assign which immigration point, working randomly for the sake of simulation.

After that, another assign module named "Assign img flag to 1" is used at the "true" logic end to set the flag with the value of 1 (active or available counter). That flag is held in a global variable array named "imgflag" with length of 132. "nflag" which was assigned earlier is used to specify which flag in the array and is represented as imgflag(nflag). For instance if the second flag is active that can be represented as imgflag(2) = 1 (as illustrated in Figure 5.66).

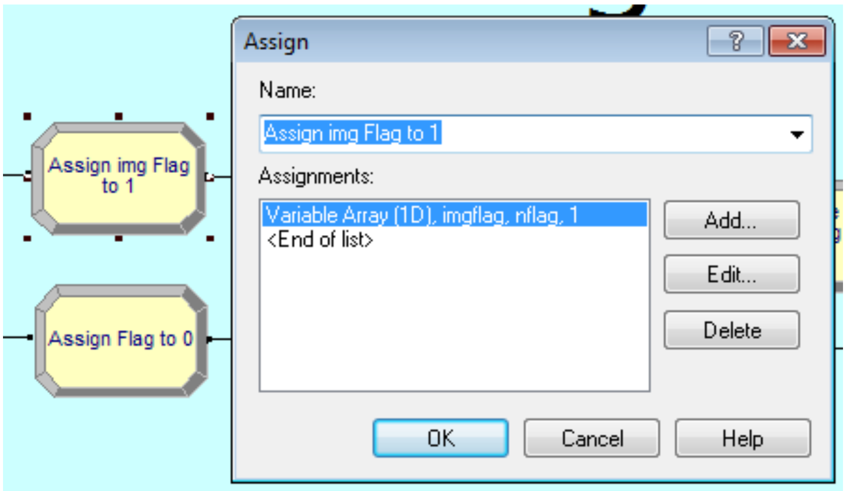


Figure 5.66 assign module used for assigning active or available immigration officer (flag=1)

On other hand, another assign module named "Assign img flag to 0" is used at the "false" logic end to set the flag with the value of 0 (not active or closed counter). That flag is held in a global variable array named "imgflag" with length of 132 as shown in Figure 5.67.

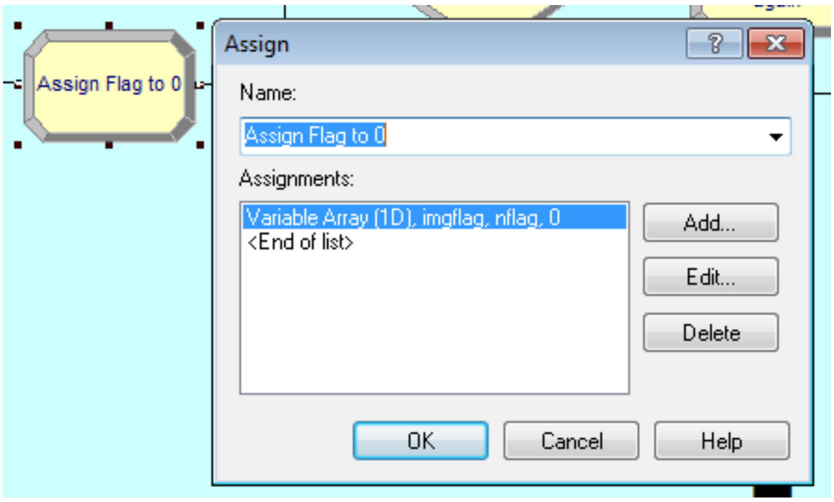


Figure 5.67 assign module used for assigning non-active or empty immigration point (flag=0)

The last controller entity is specified by using decision module named "decide if it is the Last" with "2-way by condition" type and the condition is "If nflag >= 132" (as illustrated in Figure 5.68).

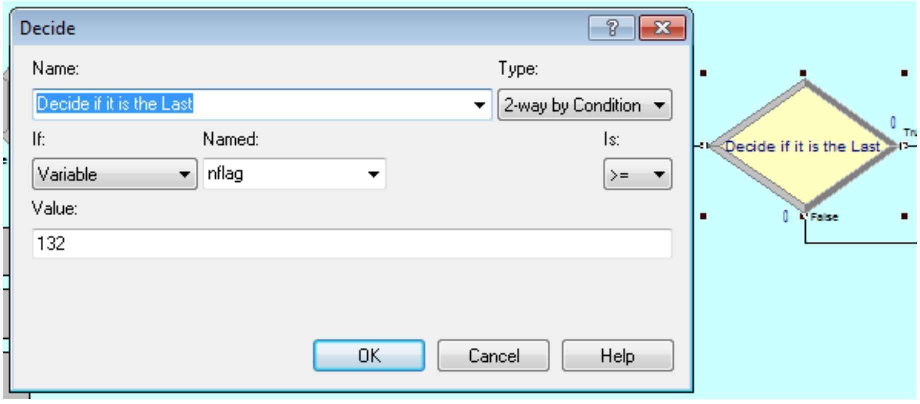


Figure 5.68 decision module is used to check if this subcontroller is the last

By knowing that the last controller is assigned already, the counter can be reset to zero as it may be used later for assigning the flag for the next day or 8 hour shift…etc. For that an assign module is attached with name" assign the counter nflag 0 again" which equals "nflag with zero" as shown in Figure 5.69.

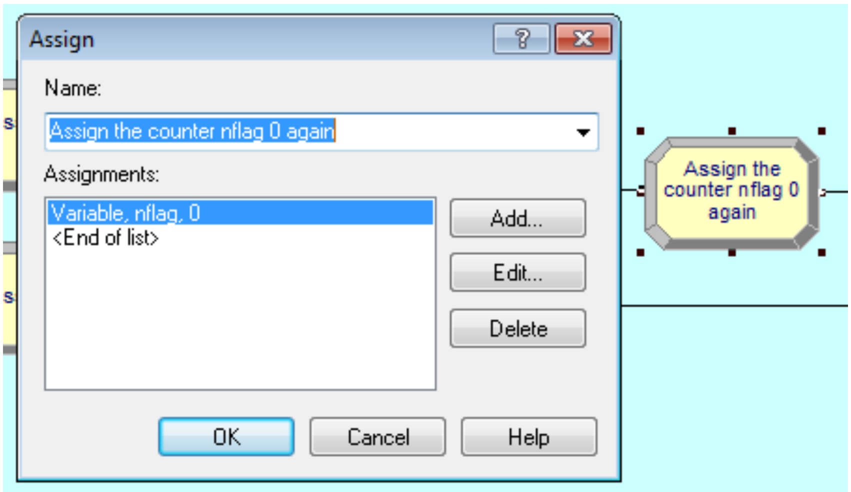


Figure 5.69 assign module that assigns 0 to the counter which might be refreshed in the new shifts of the immigration officers

Finally, a dispose module named "Dispose img flag" is attached to finish the job by terminating created entities in the end as shown in Figure 5.70.

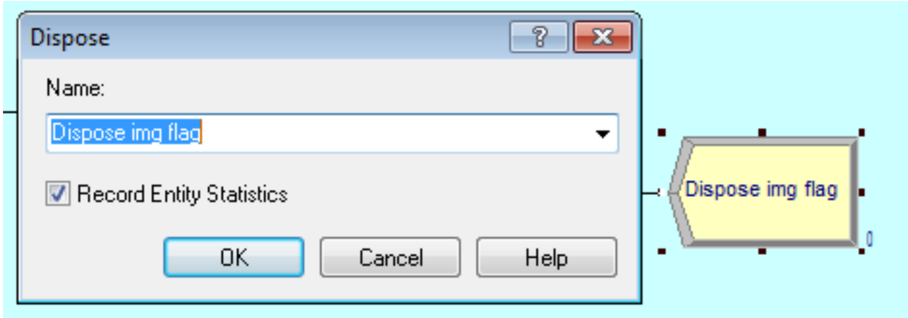


Figure 5.70 dispose module that disposes controllers and sub controllers.

5.15 Block6: assign a picture for passenger after collecting his bags

Block 6 is used to modify the passenger entity's image to one that represents their status once they get their luggage, and have passed through the baggage handling and collecting process handled in Blocks 8, 9 and 10. These blocks (mainly 10) will direct passengers who have found their luggage to Block 6 to get their status appearance changed (see Figure 5.71).

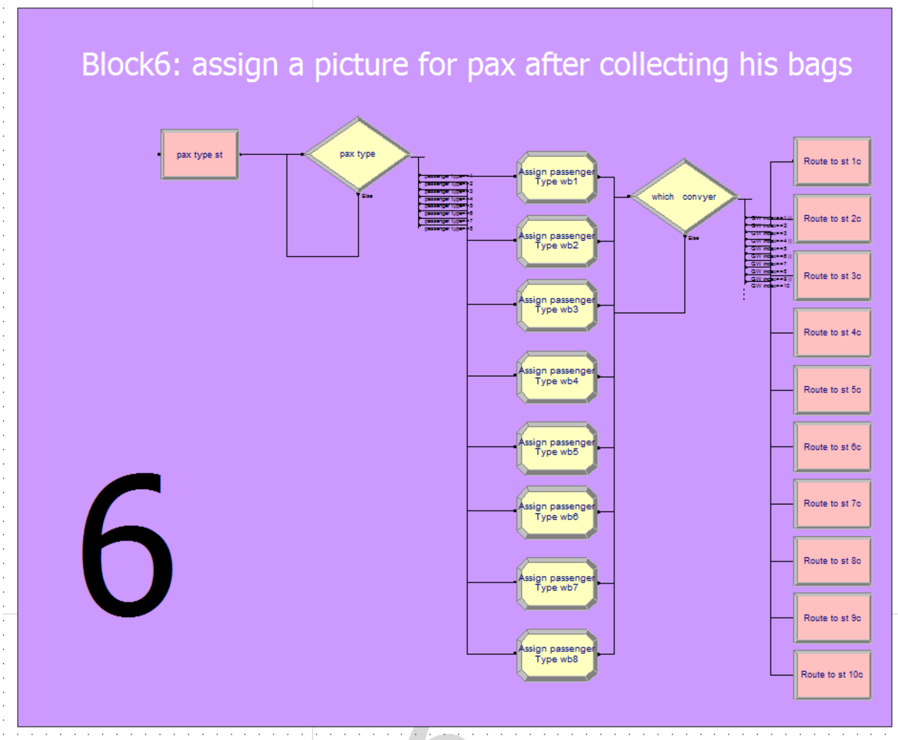


Figure 5.71 Logic flowchart of block 6 modules.

That can be done in this block by using a decision module followed by eight assign modules, with eight different colours used to represent passengers. The decision module is named "pax type" and the type is set to be "N-way Condition" with eight expression conditions "Passenger type =1, 2, 3, …, 8" (as shown in Figure 5.72).

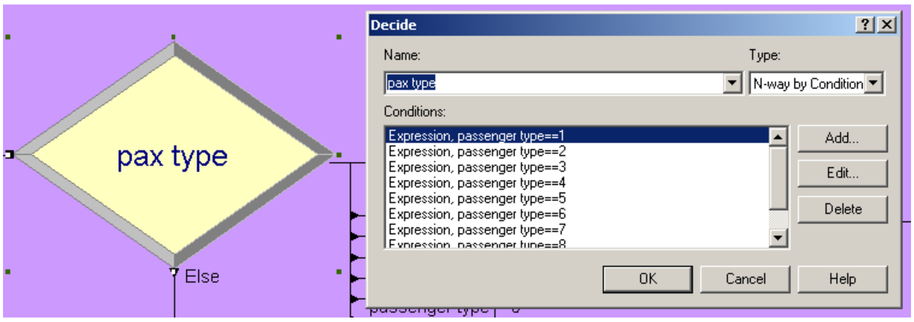


Figure 5.72 Decision module for passenger type separation.

5.16 Block 7: Direct each flight passengers to associated conveyer

According to arrival flight allocation in the jet way, this block will assign a suitable conveyor belt as it needs to be close to the passengers' walking path. This block is meant to be called from the main luggage block (Block 10). Block 7 contains 13 blocks to simulate the mentioned logic as shown in Figure 5.73. The block starts with a station module which receives entities and an assign module that captures the time, then a decision module identifies which conveyor belt is nearest to the arrival jet way based on 10 expression conditions as is revealed in Table 5.13. After that a route module will lead to a specified belt.

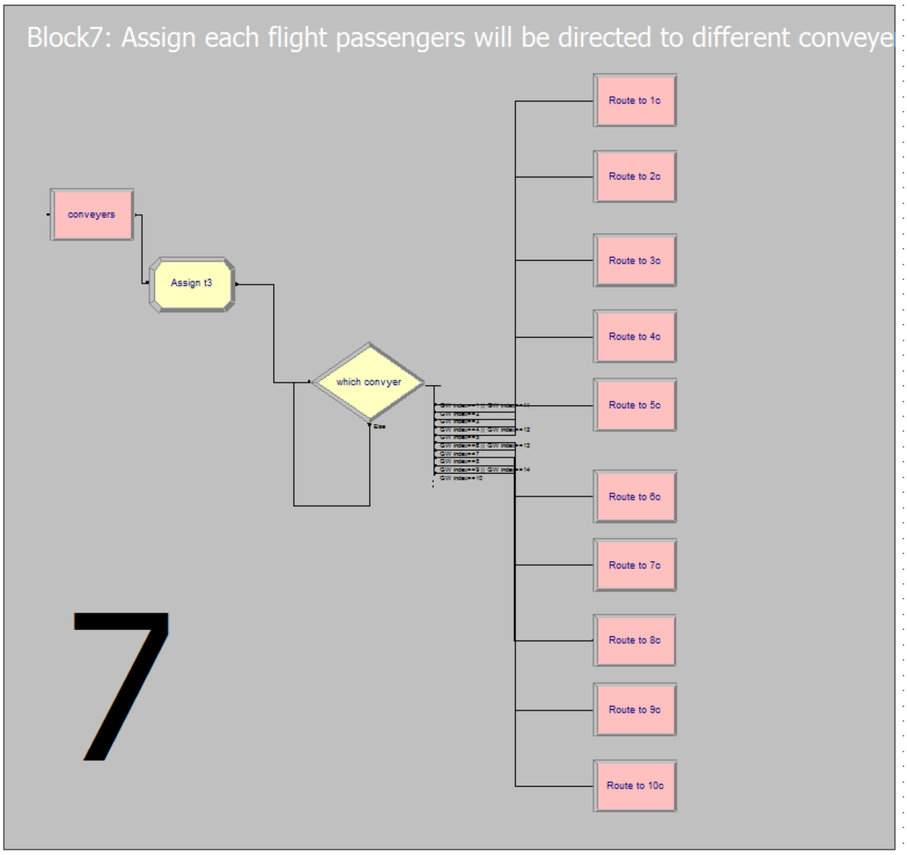


Figure 5.73 Logic flowchart of block 7 modules.

Each conveyor is assigned to a specific jet way as it is located nearest to the walking path for that flight. Passenger expressions are listed in Table 5.13.

Table 5.13 Decision module expression

Conveyor No	Expression
conveyor 1	GW index==1 || GW index==11
conveyor 2	GW index==2
conveyor 3	GW index==3
conveyor 4	GW index==4 || GW index==12
conveyor 5	GW index==5
conveyor 6	GW index==6 || GW index==13
conveyor 7	GW index==7
conveyor 8	GW index==8
conveyor 9	GW index==9 || GW index==14
conveyor 10	GW index==10

These ten expressions are filled in conditions in the field of "which conveyer" in a decision module with "N-way by Condition" type as is illustrated in Figure 5.74.

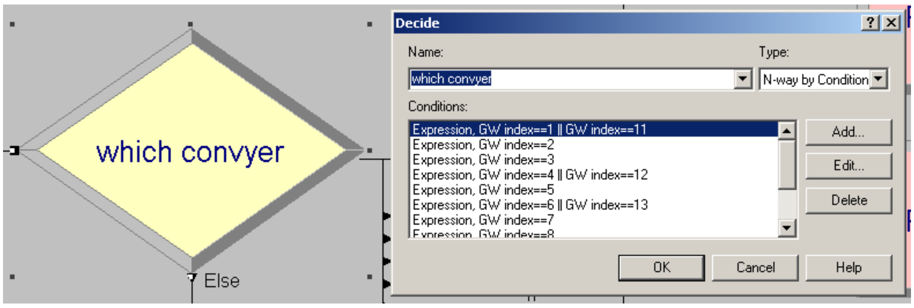


Figure 5.74 Decision module for passenger separation by their jet way gate.

That is connected to a "route" module named "Route to 1c" with route time set to be "Transfer Time" and with "minutes" in the units field, while the destination type is set to "station" with station name of "station 1c", and likewise for the first other nine route modules (see Figure 5.75).

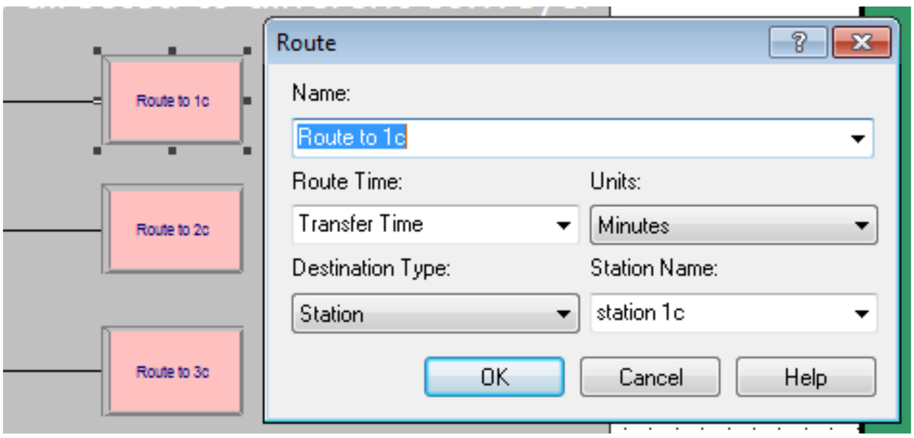


Figure 5.75 Route module for conveyor belts

5.17 Block 8: simulates baggage cart transfer by handling agent

This block contains 6 modules and represents the cart as it is released from the plane and prepared to makeup area to be sent to conveyor belts in the airport terminal (see Figure 5.76).

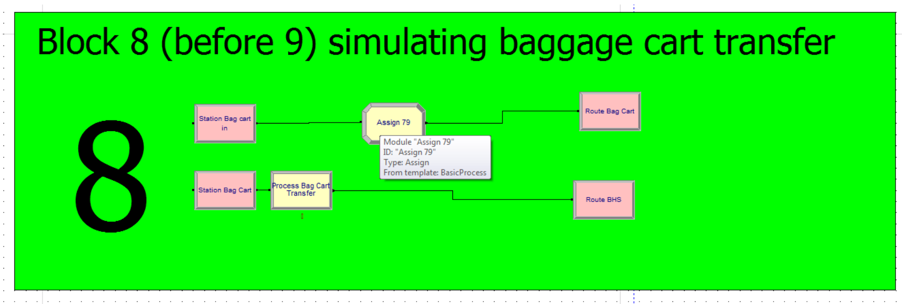


Figure 5.76 Logic chart of Block 8 baggage cart transfer.

Firstly, a station module named "station bag cart in" with type "station" is created to receive entities from Block 3 route modules as shown in Figure 5.77.

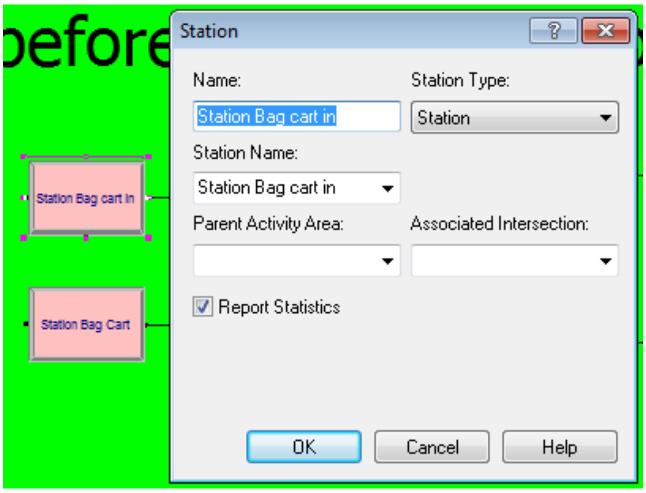


Figure 5.77 Station module named "Station Bag cart in".

Then an assign module is linked to attach a picture of the cart, with the name picture.box from the entity pictures as illustrated in Figure 5.78.

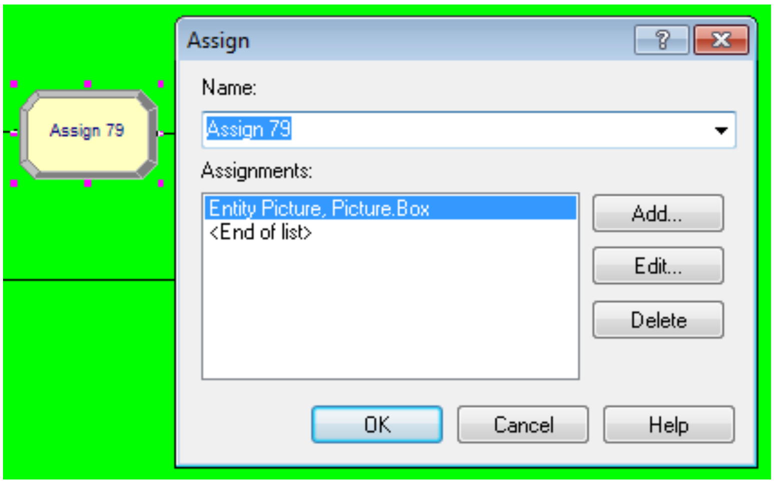


Figure 5.78 Assign module to assign entity pictures.

That picture is illustrated in the following figure with value of "Picture.Box" from the Libraries included in Arena at the file named "basicprocess.pld" (see Figure 5.79).

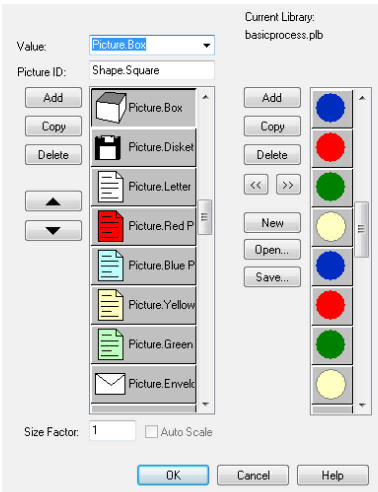


Figure 5.79 Selecting and adding cart picture.

After that a route module is created to forward the cart to the process module; the main purpose of the route station is to allow an animation for moved carts as shown in Figure 5.80.

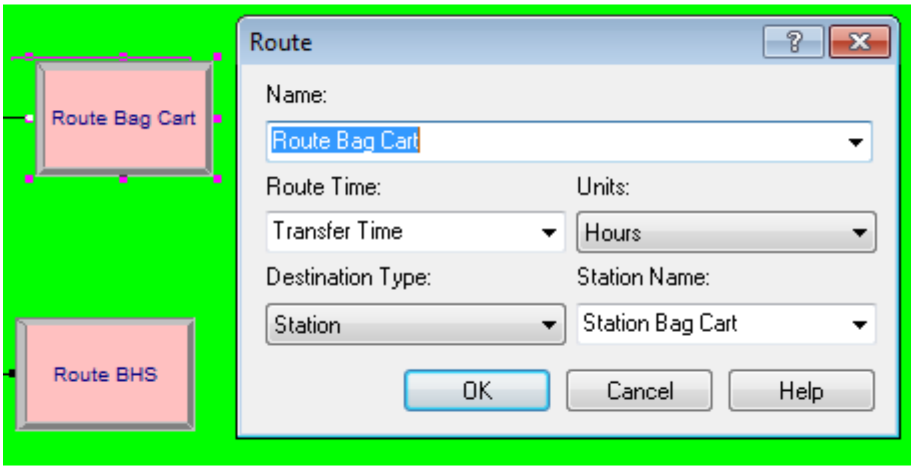


Figure 5.80 Route module named "Route Bag Cart".

Next a station named "station bag cart" with "station" type is connected to receive entities into the process module as shown in Figure 5.81.

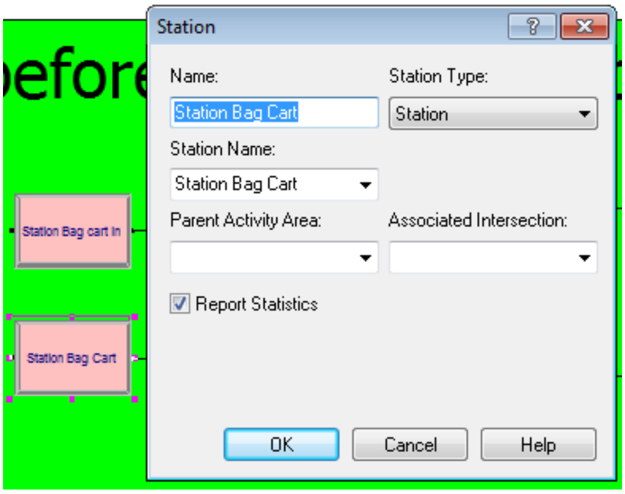


Figure 5.81 Process module named "Station Bag Cart".

The process module is named "Process Bag Cart Transfer" with type "Standard" and logic action "Delay" following a triangular distribution as explained in Figure 5.82.

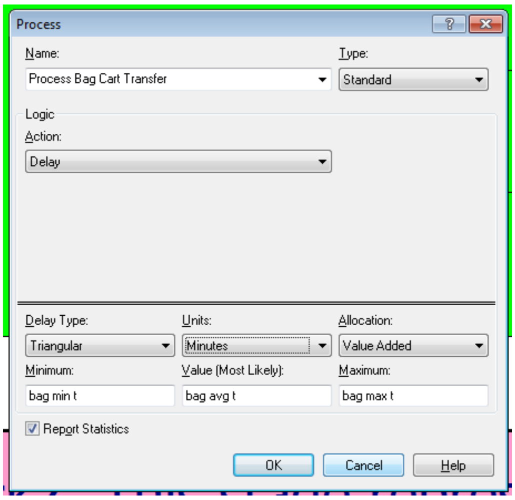


Figure 5.82 Baggage cart process module configuration.

Finally, a route module named "Route BHS" is used to transfer baggage to the station named "station bhs" located in Block 9 which direct flight baggage to different conveyors as shown in Figure 5.83.

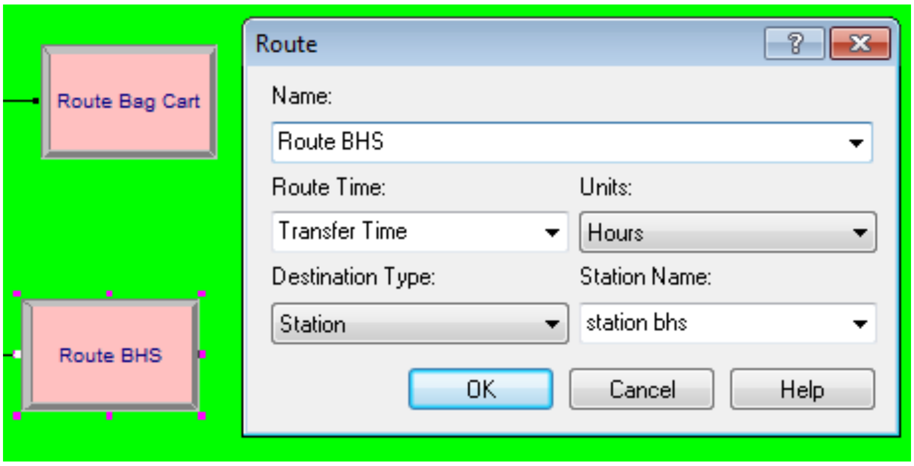


Figure 5.83 Route module named "Route BHS".

5.18 Block 9: flight baggage directed to different conveyors

This block has 10 related block and has the same purpose as Block 7; yet, this block is concerned with luggage in place of passengers. On the other hand, the block follows the same logic as Block 7. This block contains 13 modules and ten of those are route stations, and also it starts with one station module, a separate module and a decision module as explained in Figure 5.84.

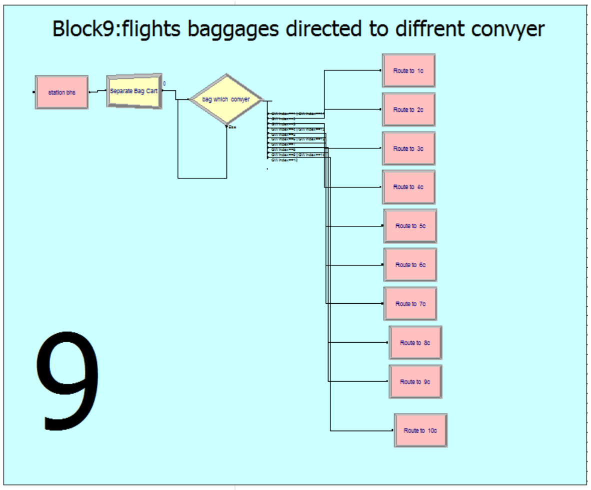


Figure 5.84 Logic flowchart of Block 9 modules.

5.19 Block 10: The main luggage claim block

The block for luggage claim is found to be one of the most complex logic blocks since it needs a logic that is capable of identifying each passenger with their associated baggage. Arena simulates that job by the “match” and “batch” modules as it will be revealed later. Block 10 consists of 72 modules that contain ten stations and a route module (see Figure 5.85).

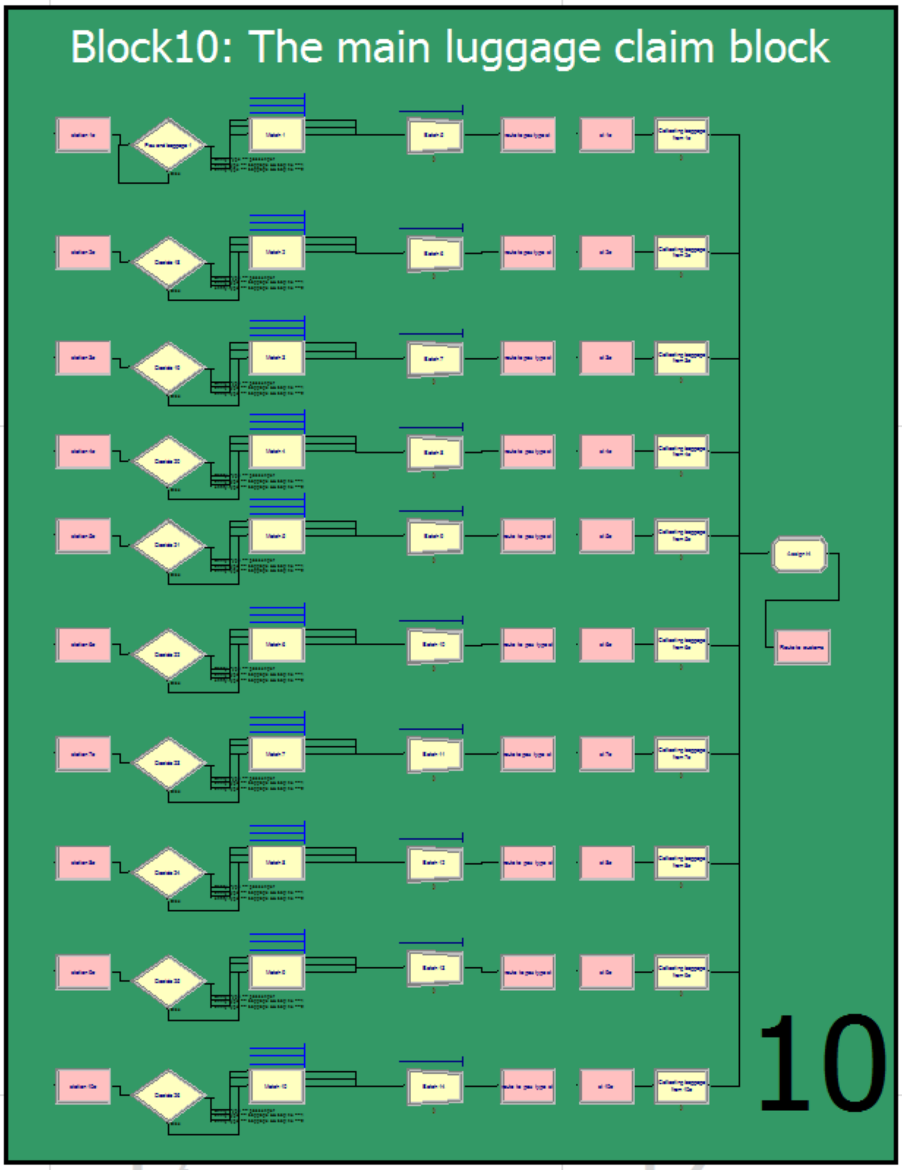


Figure 5.85 Logic flowchart of block 10 modules.

The logic can be separated to ten identical sections; each section contains 7 modules in linked to the assign and the route module which act like a conveyor belt as illustrated in Figure 5.86.

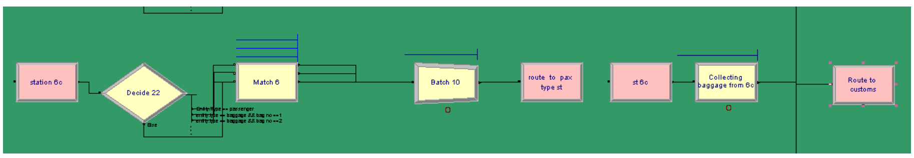


Figure 5.86 Logic flowchart of each conveyor in block 9 modules.

Each “decide” module categorise entities by their type and direct them to three ends which all connected to a “match” module of that specific conveyor belt. Decision module named ”Pax and baggage 1,2,…,10" with "N-way condition" type. Three expression condition added then the separation function takes place as illustrated in Figure 5.87.

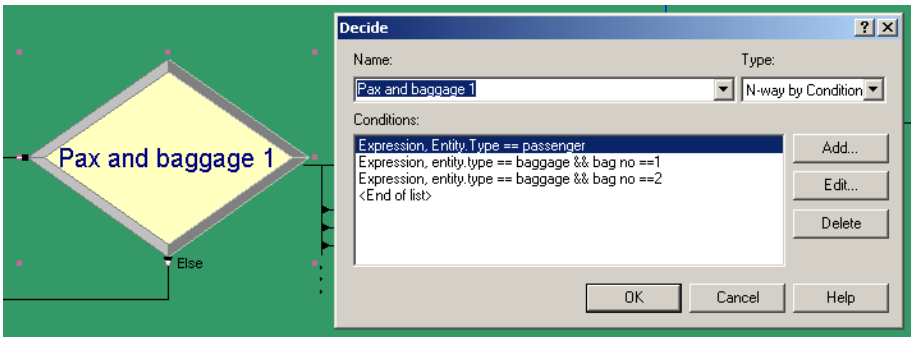


Figure 5.87 Decision module named "Pax and baggage 1".

Then a match module is chosen to be the link for the three associated items and the three inputs are sorted based on their attributes, as all of them share the same identifying attribute called "passenger index" as shown in Figure 5.88.

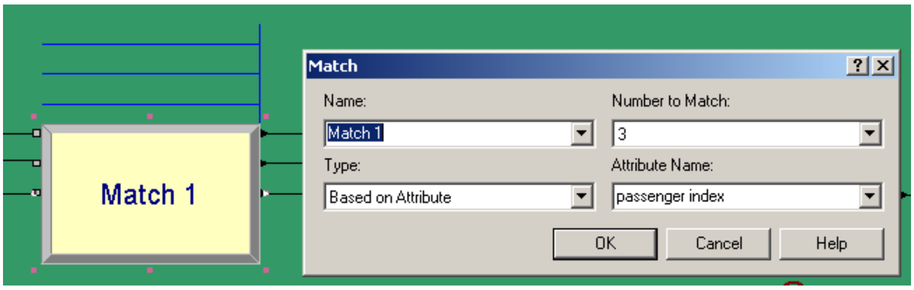


Figure 5.88 Match module used to associate passengers with their bags.

The next "batch" module is configured to be a "permanent" type as it will be kept without separation until the "dispose" module of Block 18 as shown in Figure 5.89.

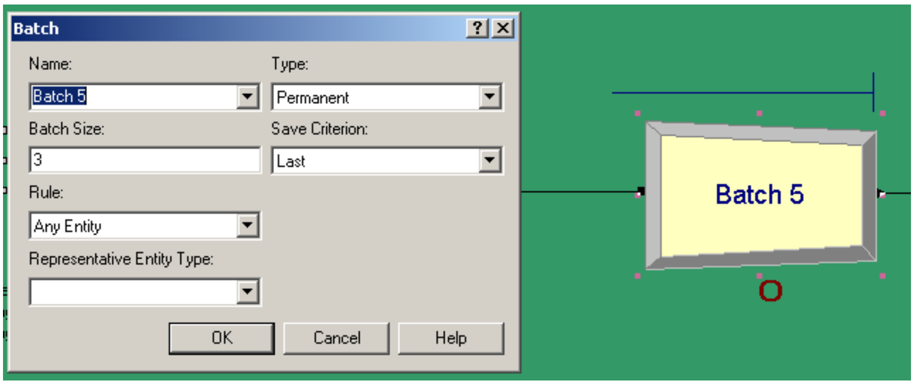


Figure 5.89 Batch module to bind associated entities from previous match.

Then, a “route” module is assigned to route the one as whole set of entities and treated as an entity they are gathered from “batch” module to Block 6, which attaches a new picture to that entity after baggage collection; this shows the passengers’ status once they have collected their luggage (see Figure 5.90).

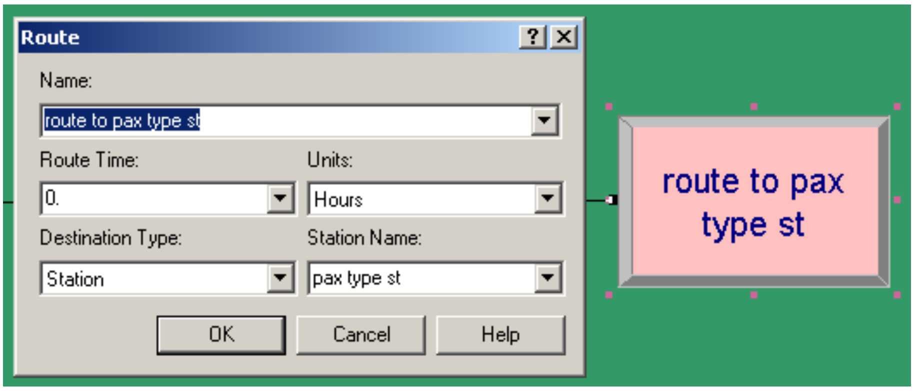


Figure 5.90 route module named” route to pax type st”.

After that, a process module named “collecting baggage from #c” for each conveyor is configured to be type “Seize Delay Release” with resource added to simulate the capacity utilization of that belt as shown in Figure 5.91.

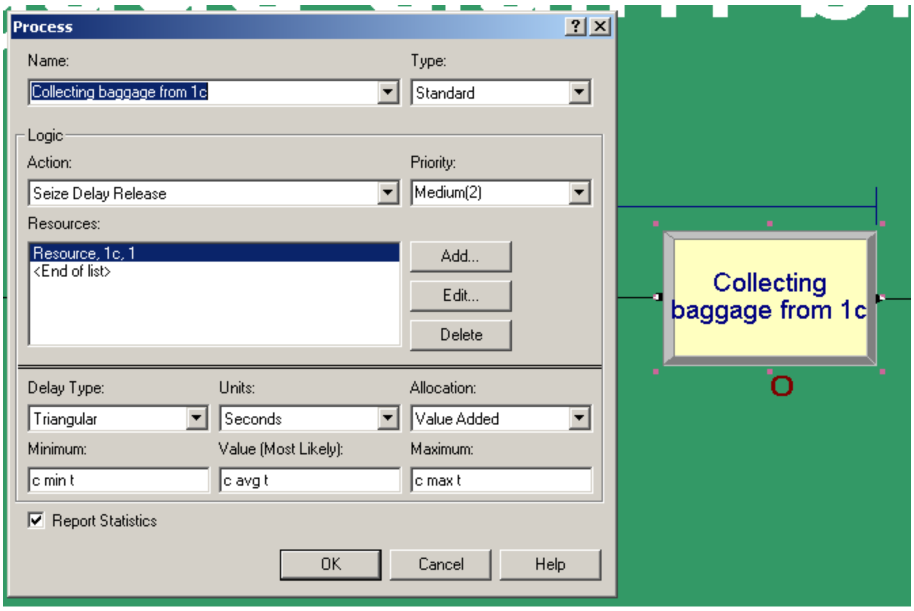


Figure 5.91 Process module named “Collecting baggage from 1c”.

The ten conveyor belts are followed by one “assign” module named “Assign t4” created to capture the time of collecting luggage process as shown in Figure 5.92.

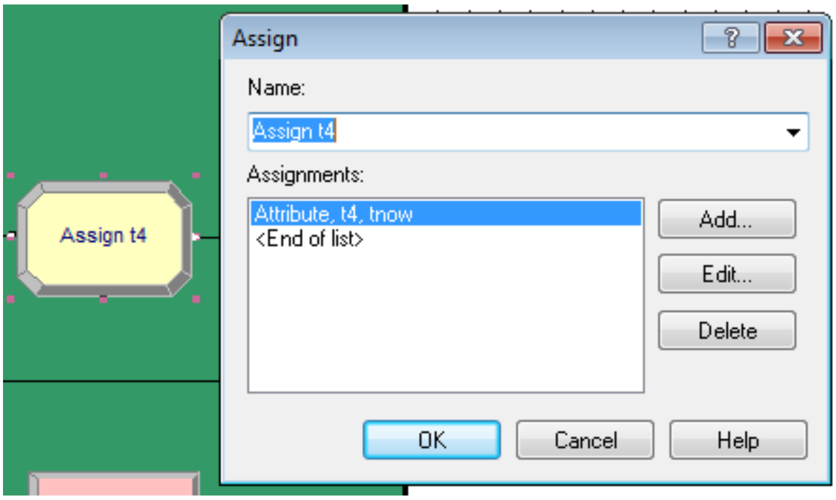


Figure 5.92 Assign module "Assign t4" to capture time "t4".

Lastly, a route module named "Route to customs" is connected to send an item to the x-ray machines to be checked by customs with destination type "station" and station name "customs" which is located in Block 11 with route time equal to "Transfer time" (see Figure 5.93).

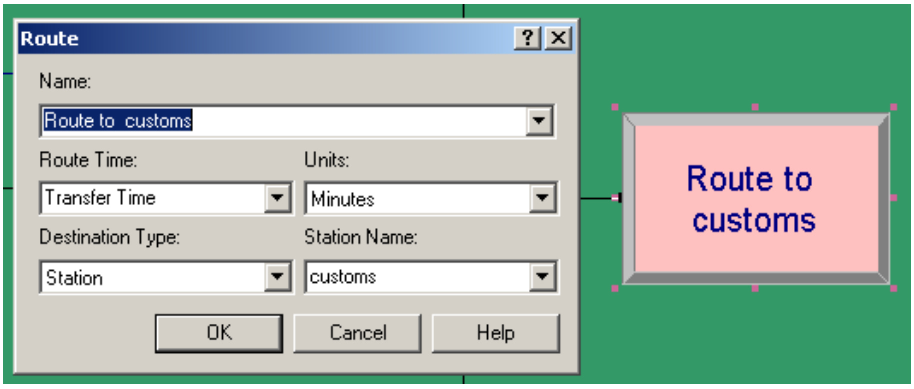


Figure 5.93 Route module named "route to customs".

5.20 Block 11: Simulates the flow of passengers in customs x-ray check points

Block 11 simulates the terminal customs as it consists of four x-ray check points and each contains four x-ray machines. Entities are led to the closest x-ray, defined from the passenger path based on which jet way he or she passed through. The logic flowchart of Block 11 is illustrated in Figure 5.94 which begins with a "station" module named "customs" and a station type "station" that is connected to the "decide" module that leads entities by considering their gate location to find the closest x-ray point.

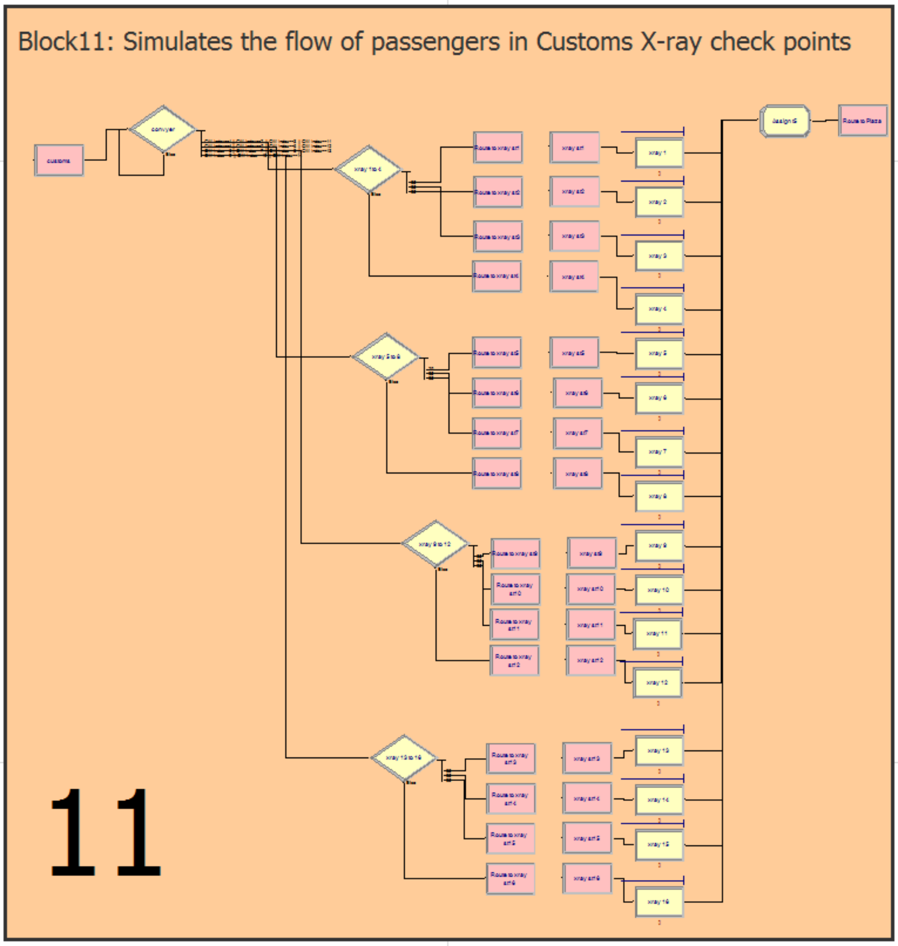


Figure 5.94 Logic flowchart of Block 11 modules.

The four x-ray points have been simulated in a similar logic flowchart shown in Figure 5.95. Each one begins with "decide" modules named: "xray 1 to 4", "xray 5 to 8", "xray 9 to 12" and "xray 13 to 16" which will distribute entities with a chance percentage of 25% for every x-ray machine.

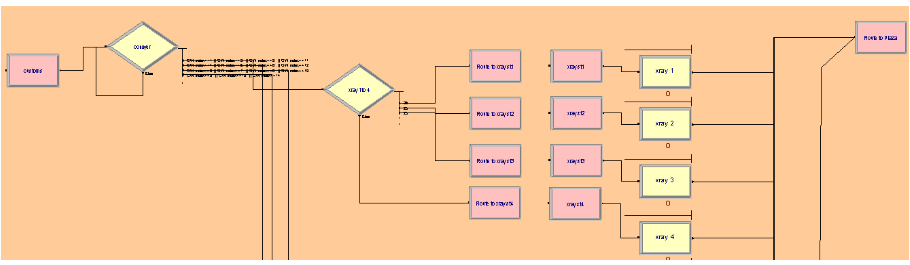


Figure 5.95 Logic flowchart of each x-ray point Block 10 modules.

Before that a "decide" module named "conveyer" is attached to the block and configured with type "N-way by condition" with four "expression" conditions as revealed in Figure 5.96.

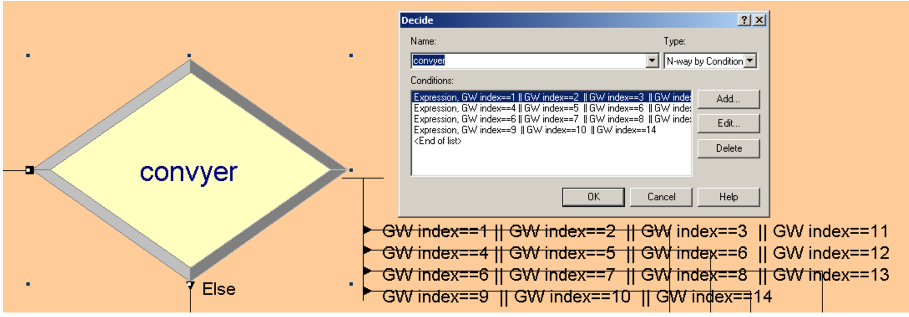


Figure 5.96 Decision module named "conveyer".

Figure 5.97 shows the configuration of the four connected "decide" modules as mentioned at the beginning.

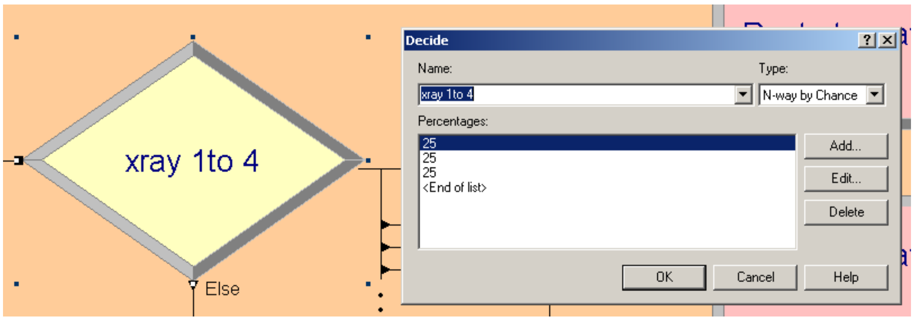


Figure 5.97 Decision module named "xray 1 to 4".

As known with any regular process, this operation would need to be allocated resource capacity that can be simulated by a "process" module with type of "seize delay release" with one resource assigned for each machine as shown in Figure 5.98.

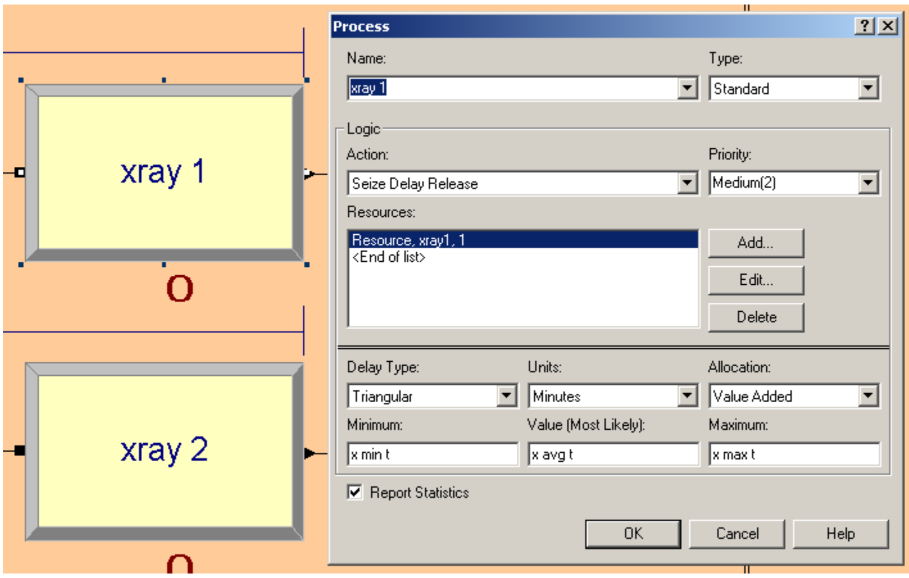


Figure 5.98 process module named "xray 1".

5.21 Block 12: The bus's movement in the airport

Bus transportation is one of the characteristics that is contained in the suggested simulation model, yet this block is simply approached only once all the jet ways are engaged or the arrived aircraft is not capable of being connected to the jet way (see Figure 5.99).

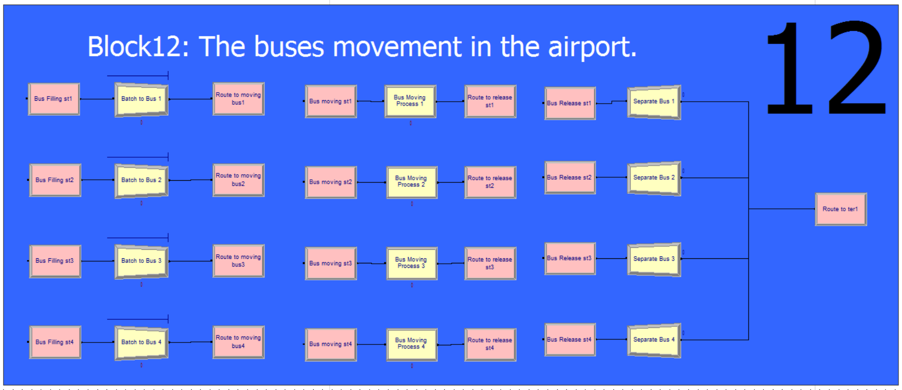


Figure 5.99 Logic flowchart of block 12 modules.

The batch module is utilised for allowing buses to collect passengers by considering them as one item in total before a different bus will come to collect the remaining passengers in the same way, as shown in Figure 5.100.

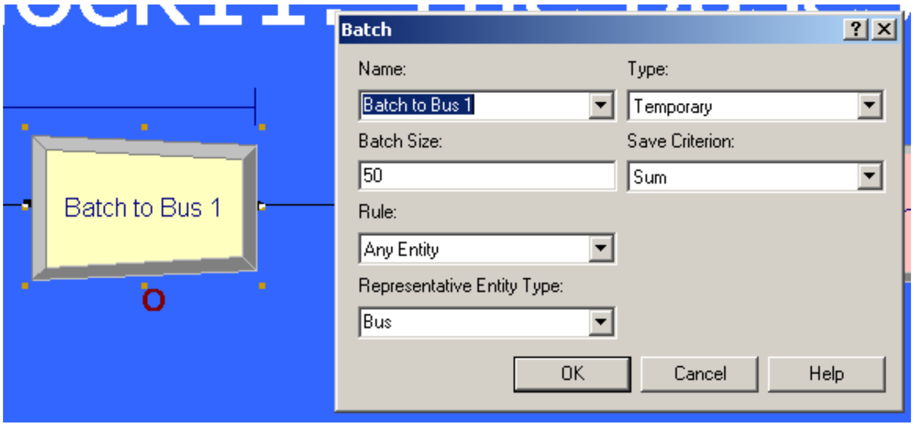


Figure 5.100 Batch module named "Batch to bus 1".

Then a "process" module named "bus moving process 1" is used to simulate bus transportation time needed to reach the terminal with "standard" type and logic action assigned to "delay" as shown in Figure 5.101.

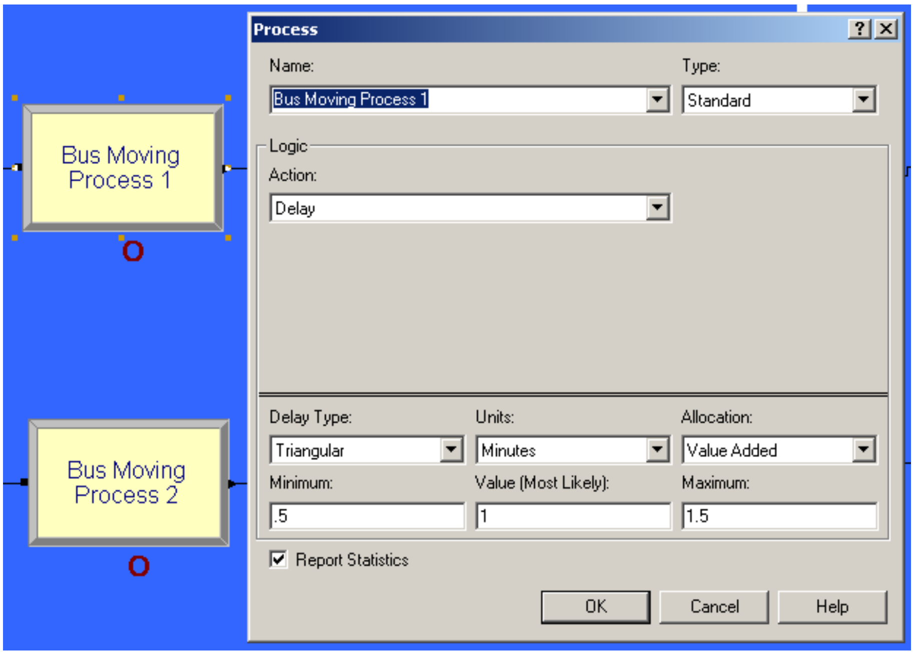


Figure 5.101 Process module named "Bus Moving Process 1".

After that a "separate" module is attached to release the entities from the buses to allow them to enter the building of the airport terminal. The batch type is configured to be "split existing batch" and entities' attributes should be retained as their initial values (see Figure 5.102).

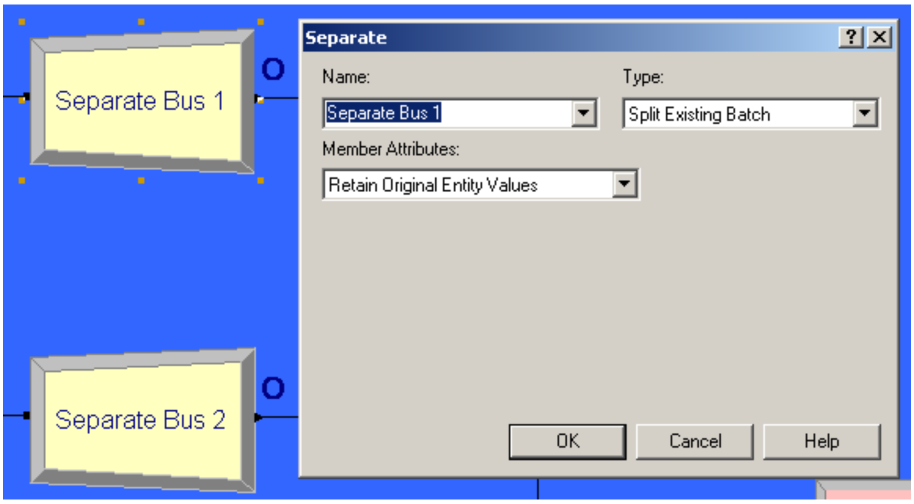


Figure 5.102 separate module named "Separate Bus 1"

5.22 Block18: Shopping and dispose.

The last block is named "shopping and dispose"; the shopping process is however not meant to be focused on in this study. It is not considered to be one of the crucial objectives as it is profitable, and capacity is not an issue due to the huge area assigned to it; it has however been involved to give a holistic view of the practice as advised by Correia et al. (2008a, 2008b). The shopping process is represented by a process module that considers the time of the shopping as an activity. The last and main module in this is the "dispose" module to allow passenger entities and their baggage to exit the system in this step of the simulation (see Figure 5.103).

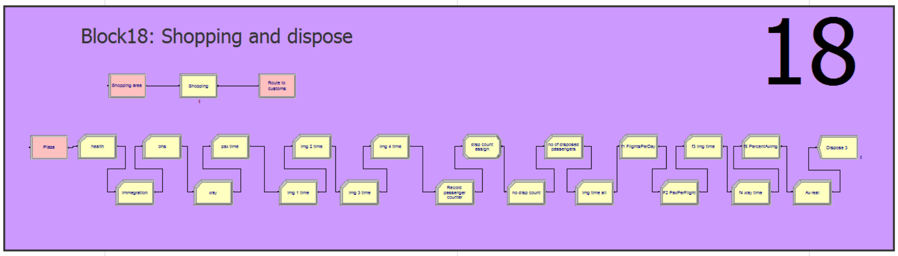


Figure 5.103 Logic flowchart of Block 18 modules.

5.23 Summary

By the end of Block 18, the simulation model is completed. The process started with using simulation steps in the designed route-station blocks and analysing gathered data from the airport terminal. An "Input analyser" is a supportive software that has done the distribution expression recognising in that area. In addition, the re-adjustment capability was considered to get the model prepared for the next required step for applying sets or groups of trials (different 'what if' scenarios) as can be illustrated in the following chapter for regression and fuzzy logic study's sake. "Record" modules will help to gain readings of some factors captured at specific times to allow the production of a report to assist this research. There are many additional ways of creating DES models and there are various diverse environments which could be studied as replications of this research, to allow for more alternatives and to provide more performance optimisation room to develop. Advantages and disadvantages will be discussed after the results chapter.

Chapter 6 Results

6.1 Introduction to simulation results

Arena is known by its well-detailed results for each simulation executed on it, powered by crystal report. This chapter will reveal out data of running the simulation model firstly to show the different factors. Independent variables (or predictors) that used to predict some other variable are identified here as "FlightsPerDay", "PaxPerFlight", "img_time", "x_ray_time" and "PercentAvImg" while the dependent (or predicted) variables that can be calculated by a using the independent variable clarified as "no disp count", "pax_time" and "Record passenger counter", in addition to a capacity ratio that can be calculated from two variables as described in Table 6.1. A series of different situations and scenarios are carried out in Arena to get outputs that can be analysed later, for preparing a mathematical presentation of the system behaviour by changing the inputs of that simulation model. This mathematical model can allow the optimisation study on the system as it has been set as an aim of this research. Copies of detailed reports are included in the appendix section. In existing running configuration setting it has been considered number of replications to be as high as possible. However it cannot be performed in some cases due to the huge number of modules, and large number of simultaneous entities, particularly on peak and highly utilised days where there are a lot of in-system entities (example of that shown in Figure 6.1). The number of scenarios aimed to be done was 500 in about 80 groups, although only 253 trials in 40 groups were carried out; the rest were not applied due to the limitation on the number of objects that can be handled (see Figure 6.1).

```
ERROR:

Entity: 1102
A runtime error was detected at time 1401.8 at the following block:

 * 2053 235$           DUPLICATE,100-100:1,11463$,100:NEXT(11462$);

Dimension of internal array ISET exceeded.
There is not enough space to complete processing your model.
Use the Array Sizes page in the Run/Setup dialog to
increase the space allocated, then recheck your model.
```

Figure 6.1 runtime error was detected when software entity capacity exceeded.

The "Run setup" configuration setting was done by assigning the replication parameters to have a high replication, mostly starting with 10 days unless an error is found as mentioned that leads to a reduced number of replications. The "initialize between replications" option is set to be "system". Replication length is set to be a day, "24 hours", as the airport works 24/7 and "hours per day" set to be "24 hours" while the base time unit set to be minutes as shown below in Figure 6.2.

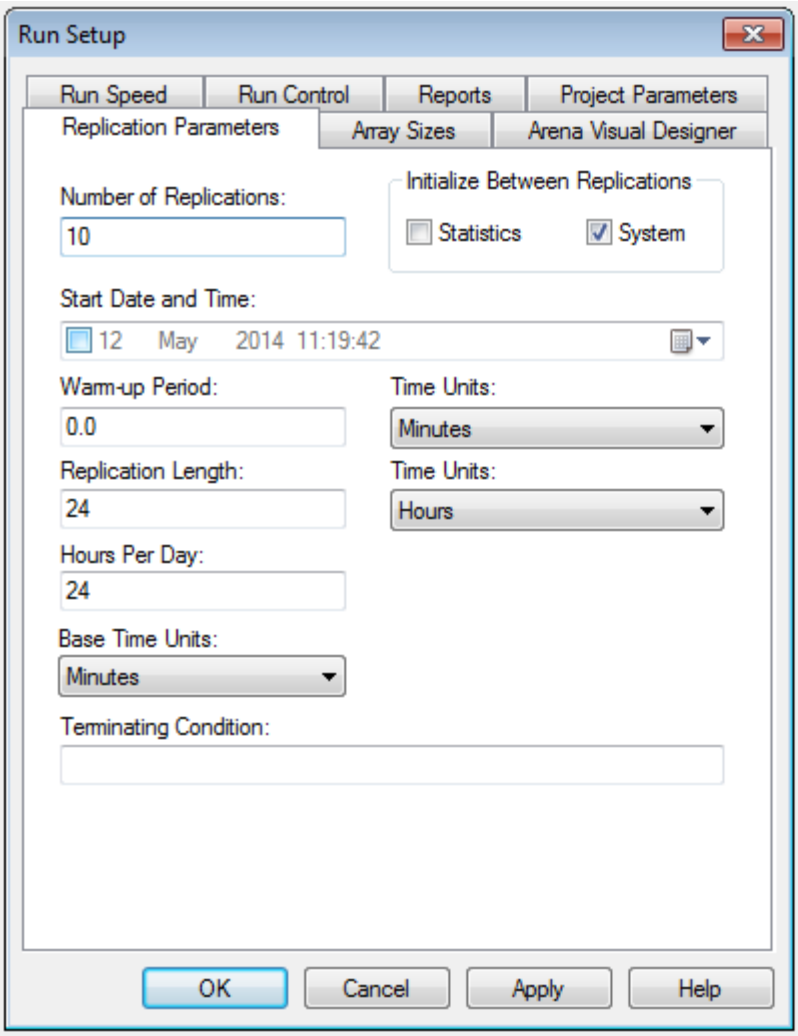
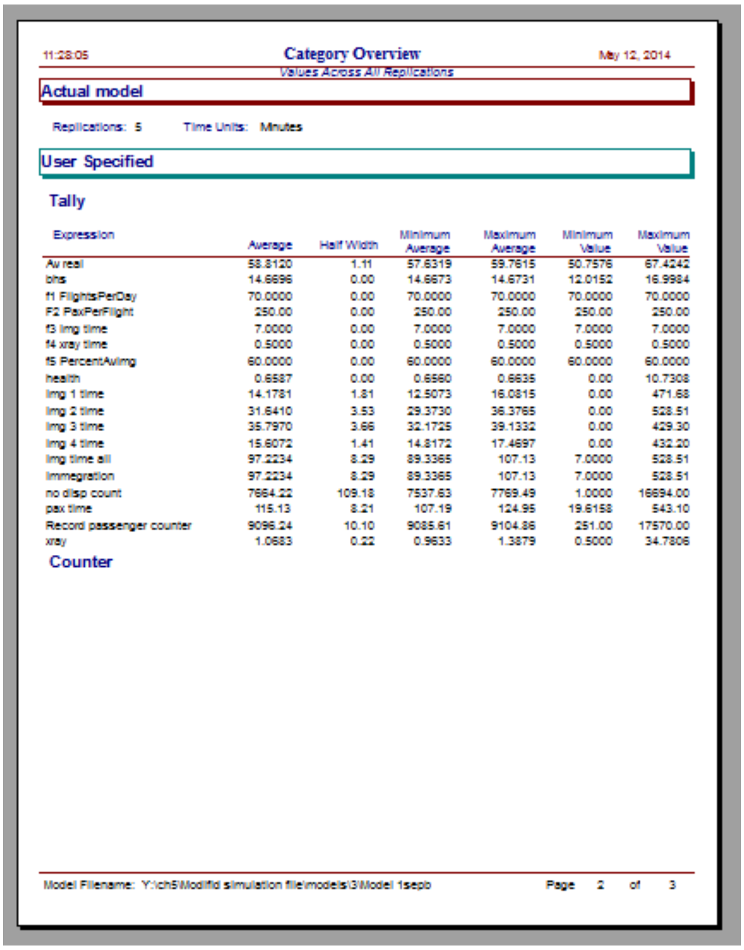


Figure 6.2 Run Setup Configuration settings

After running the simulation model, a report was generated for the specified number of replications, and those report parameters from "Project Parameters" in the run setup window are shown in Figure 6.2 Run Setup Configuration settings. User- specified category parameters are mostly more relevant as they have been captured by the user's decision, in this case "assign" and "record" modules used to carry out these variables which are: "Av real", "bhs", "f1: FlightsPerDay", "f2: PaxPerFlight", "f3: img_time", "f4: x_ray_time", "f5: PercentAvImg", "health", "img 1 time", "img 2 time", "img 3 time", "img 4 time", "img_time all", "immigration", "no disp count", "pax_time", "Record passenger counter" and "x-ray" illustrated in Figure 6.3 and Table 6.1.



11:28:05 Category Overview May 12, 2014

Values Across All Replications

Actual model

Replications: 5 Time Units: Minutes

User Specified

Tally

Expression	Average	Half Width	Minimum Average	Maximum Average	Minimum Value	Maximum Value
Av real	58.8120	1.11	57.6319	59.7615	50.7576	67.4242
bhs	14.6696	0.00	14.6673	14.6731	12.0152	16.9984
f1 FlightsPerDay	70.0000	0.00	70.0000	70.0000	70.0000	70.0000
F2 PaxPerFlight	250.00	0.00	250.00	250.00	250.00	250.00
f3 img time	7.0000	0.00	7.0000	7.0000	7.0000	7.0000
f4 xray time	0.5000	0.00	0.5000	0.5000	0.5000	0.5000
f5 PercentAvImg	60.0000	0.00	60.0000	60.0000	60.0000	60.0000
health	0.6587	0.00	0.6560	0.6635	0.00	10.7308
img 1 time	14.1781	1.81	12.5073	16.0815	0.00	471.68
img 2 time	31.6410	3.53	29.3730	36.3765	0.00	528.51
img 3 time	35.7970	3.66	32.1725	39.1332	0.00	429.30
img 4 time	15.6072	1.41	14.8172	17.4697	0.00	432.20
img time all	97.2234	8.29	89.3365	107.13	7.0000	528.51
immegration	97.2234	8.29	89.3365	107.13	7.0000	528.51
no disp count	7664.22	109.18	7537.63	7769.49	1.0000	16694.00
pax time	115.13	8.21	107.19	124.95	19.6158	543.10
Record passenger counter	9096.24	10.10	9085.61	9104.86	251.00	17570.00
xray	1.0683	0.22	0.9633	1.3879	0.5000	34.7806

Counter

Model Filename: Y:\ch5\Modifid simulation file\models\3\Model 1sepb Page 2 of 3

Figure 6.3 Sample page from detailed Arena simulation after running it.

Table 6.1 detailed output of sample Arena simulation

Expression	Average	Half Width	Minimum Average	Maximum Average	Minimum Value	Maximum Value
Av real	58.8120	1.11	57.6319	59.7615	50.7576	67.4242
Bhs	14.6696	0.00	14.6673	14.6731	12.0152	16.9984
f1: FlightsPerDay	70.0000	0.00	70.0000	70.0000	70.0000	70.0000
f2: PaxPerFlight	250.00	0.00	250.00	250.00	250.00	250.00
f3: img_time	7.0000	0.00	7.0000	7.0000	7.0000	7.0000
f4: x_ray_time	0.5000	0.00	0.5000	0.5000	0.5000	0.5000
f5: PercentAvImg	60.0000	0.00	60.0000	60.0000	60.0000	60.0000
Health	0.6587	0.00	0.6560	0.6635	0.00	10.7308
img 1 time	14.1781	1.81	12.5073	16.0815	0.00	471.68
img 2 time	31.6410	3.53	29.3730	36.3765	0.00	528.51
img 3 time	35.7970	3.66	32.1725	39.1332	0.00	429.30
img 4 time	15.6072	1.41	14.8172	17.4697	0.00	432.20
img_time all	97.2234	8.29	89.3365	107.13	7.0000	528.51
immigration	97.2234	8.29	89.3365	107.13	7.0000	528.51
no disp count	7664.22	109.18	7537.63	7769.49	1.0000	16694.00
pax_time	115.13	8.21	107.19	124.95	19.6158	543.10
Record passenger counter	9096.24	10.10	9085.61	9104.86	251.00	17570.00
X-ray	1.0683	0.22	0.9633	1.3879	0.5000	34.7806

As has been indicated, 253 simulation scenarios were considered. These scenarios were carried out as groups, where each group has one variable which is changed, while other variables are fixed at certain values. Some constraints were considered, such as the capacity limitation of handled entities in the Arena software. Another aspect to be considered is the variable range, for example the number of flights per day, or "F/D", varies from 10 to 160 due to terminal operation capacity and authorities' regulations. The number of passengers per flight, or "P/F", is assumed to vary from 100 to 500 as the Airbus A380 can carry about 525 passengers in its current seating format (www.airbus.com 2014), (Bazargan et al. 2008). Other ranges can be seen in Table 6.2.

Table 6.2 ranges for variables

	F/D	*P/F*	*img_t*	*x_ray_t*	*av*	*disp_pax*	*pax_t*	*total_pax_no*	*cap*
Min	10	100	1	0.5	13	407.5	23.97	1507.5	0.230
Max	160	500	20	20	100	17544.3	723.96	18133.64	0.993

F/D: *number of flights arriving at the terminal per day*
P/F: *number of passengers per flight*
img_t: *immigration and passport check process time*
x_ray_t: *x-ray and customs check process time*
av: *percentage of immigration and passport check*
disp_pax: *number of disposed passengers from airport terminal*
pax_t: *passengers total time spent in the terminal*
total_pax_no: *total number of passengers generated in the simulation*
cap: *capacity ratio of disposed passengers to total number of passengers*

While creating these scenarios an adaptive neuro-fuzzy logic model was generated and assessed to identify areas needed to be covered from the input output graph that simulates the mathematical model of the system, which can show illogical results for undefined areas, where more trials are required. The summary of input trials are presented in

Table 6.3 as 40 groups where the variable parameter is highlighted in each row and named x and that range defined in the "from" and "to" columns. From the values of t-test column it can be said that as the system is utilized more, the trial will better reflect the behaviour of the system.

Table 6.3 Summary of input groups by fixing all variables and changing one of them

	F/D	*P/F*	*img_t*	*x_ray_t*	*av*	*x from*	*x to*	*t-test*
G1	30	300	3	1.5	x	25	100	0.000483
G2	40	200	x	1	100	1	20	1.53E-05
G3	100	219	x	0.5	100	1	7	7.83E-10
G4	100	219	1	0.5	x	100	20	0.20668
G5	100	x	3	1.5	100	100	170	0.001263
G6	100	x	1.5	1.5	100	100	160	0.029525
G7	134	219	x	0.5	100	6	1	1.89E-05
G8	160	219	x	0.5	100	4	1	0.000251
G9	29	219	x	0.5	100	1	6	1.22E-14
G10	14	200	1	x	100	20	1	0.017841
G11	29	219	1	0.5	x	100	70	0.108318
G12	29	219	1	x	100	2.5	1	0.082049
G13	40	200	4	1	x	30	100	0.092969
G14	20	120	2.5	x	100	1	10	0.140913
G15	25	125	x	1.5	100	1	10	9.35E-13
G16	25	125	2	x	100	7	0.5	0.01958
G17	40	x	4	1	100	100	500	0.011249
G18	50	x	3	1.5	100	100	300	2.37E-07
G19	x	300	3	1.5	100	40	10	0.002658
G20	x	300	5	1.5	100	10	50	0.009673
G21	150	130	2	1	x	100	30	0.803939
G22	100	240	4	0.5	x	100	30	0.874304
G23	100	240	2	0.5	x	100	30	0.177709
G24	100	240	4	0.5	x	100	30	0.598464
G25	115	225	5	0.5	x	100	45	0.702112
G26	30	300	10	1.5	x	30	100	0.032986
G27	30	250	10	1.5	x	30	100	0.102204
G28	35	250	10	1.5	x	30	100	0.060091
G29	35	250	9	1.5	x	30	100	0.07995
G30	35	250	10	2	x	30	100	0.018201
G31	30	300	10	2	x	30	100	0.061747
G32	60	300	1	1	x	30	100	0.082093
G33	95	300	4	0.5	x	60	100	0.204652
G34	90	230	5	0.5	x	55	100	0.862127
G35	90	200	7	0.5	x	55	100	0.870562
G36	45	300	5	1	x	25	100	0.047345
G37	95	300	4	0.5	x	60	100	0.057604
G38	30	300	7	1	x	20	100	0.228472
G39	30	300	5	1.5	x	13	100	0.000725
G40	30	250	5	1.5	x	15	100	0.008796

From

Table 6.3 it can be seen that the graph created from the adaptive neuro-fuzzy logic model shows indefinites in column av group 21 to group 40; confirmed by the chart which is presented later in this chapter. The variable x is used to present the varied predictor while others fixed in a certain group of trials. The t-test assesses whether the means of two groups are statistically different from each other. After giving this general picture about the input data, each group will be presented in detail with charts of some dependent variables along with the varied variable (changed value among the fixed ones).

6.2 Description of Input Group 1

In this group nine trials are made by fixing the four factors of F/D (number of flights per day) to 30, P/F (number of passengers per flight) to 300, x_ray_t (time for customs and x-ray scanning) to 1.5 and img_t (immigration check time) to 1.5 while changing the variable av (percentage of the available immigration staff). This should affect the pax_time or (total passenger time), although in this case the number of flights are low which means a number of 300 passengers will mostly leave the airport before the next 300 passengers are handled. X_ray_t can lead to a high number of bottlenecks in customs, and the security scanning and checking section, which add a delay as shown in pax_t column in Table 6.4.

Table 6.4 Group 1 brief detailed input output table

G1	*F/D*	*P/F*	*img_t*	*x_ray_t*	*av*	*disp_pax*	*pax_t*	*total_pax_no*	*cap**
1	30	300	3	1.5	100	4310.5	131.35	5132.92	0.84
2	30	300	3	1.5	90	4249	88.4947	4805.9	0.88
3	30	300	3	1.5	80	4187.5	117.97	4931.2	0.85
4	30	300	3	1.5	70	4063	166.11	5151.45	0.79
5	30	300	3	1.5	60	4345	115.51	5069.54	0.86
6	30	300	3	1.5	50	4142.5	135.39	4995.64	0.83
7	30	300	3	1.5	40	4241.5	124.17	5023.31	0.84
8	30	300	3	1.5	30	4346.5	104	4999.36	0.87
9	30	300	3	1.5	25	4293	101.48	4940.99	0.87

*cap = disp_pax / total_pax_no

It can be seen an almost fixed Pax_t at 120, plus or minus about 30; as illustrated in Figure 6.4 there is some undefined behaviour which can be cleared by increasing F/D variable in the next group, which will allow a better representation of the system.

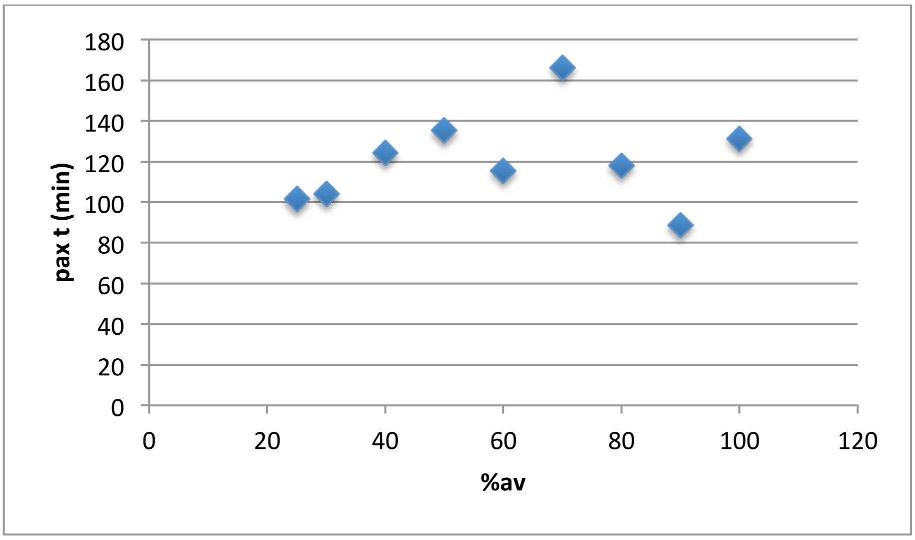


Figure 6.4 Group 1 the effect of available immigration staff ratio (av) on total passenger time (Pax_t)

6.3 Description of Input Group 2

In this group six simulations were executed by fixing the four factors of F/D (number of flights per day) to 40, P/F (number of passengers per flight) to 200, x_ray_t (time for customs and x-ray scanning) to 1 and av (percentage of the available immigration staff) to 100 while changing the variable img_t (immigration check time) from 1 to 20. This should effect the pax_time or total passenger time; in this case the number of flights are not as low as in group 1 which means 200 passengers will show some clear behaviour change that can identify the relationship as Figure 6.5 can demonstrate. X_ray_t will not lead to a high level of bottlenecks in customs and the security scanning and checking section as in group 1, and will therefore not add more delay, as is shown in Pax_t column in Table 6.5.

Table 6.5 Group 2 brief detailed input output table

G2	*F/D*	*P/F*	*img_t*	*x_ray_t*	*av*	*disp_pax*	*pax_t*	*total_pax_no*	*cap*
10	40	200	1	1	100	3949.5	42.0913	4178.55	0.95
11	40	200	3	1	100	3940.5	46.875	4197.23	0.94
12	40	200	5	1	100	3911.5	47.1442	4168.58	0.94
13	40	200	10	1	100	3919.5	56.4547	4229.82	0.93
14	40	200	15	1	100	3893	60.9906	4234.17	0.92
15	40	200	20	1	100	3811.5	80.1655	4269.97	0.89

From Table 6.5 it can be said that there is clear correlation between pax_t and img_t and this is illustrated clearly in Figure 6.5 - as img_t changes from 1 to 20 min, pax_t changes from

42 to 80 min relatively. The capacity ratio of disposed no. of passengers to total no. of created passengers shows a correlated change from 0.89 to 0.95.

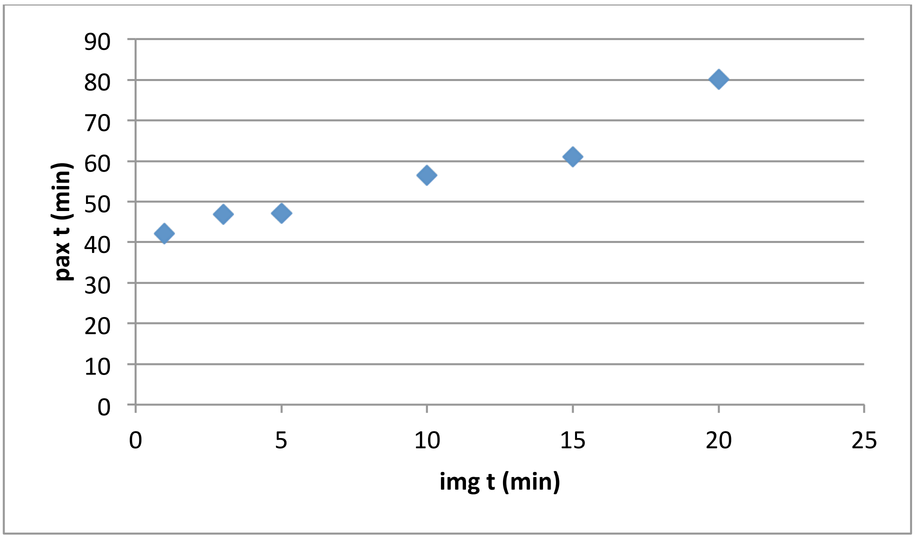


Figure 6.5 Group 2 the effect of immigration and passport check process time (img_t) on total passenger time (pax_t)

6.4 Description of Input Group 3

In this group seven trials are made by fixing the four factors of F/D (number of flights per day) to 100, P/F (number of passengers per flight) to 219, x_ray_t (time for customs and x-ray scanning) to 0.5 and av (percentage of the available immigration staff) to 100 while changing the variable img_t (immigration check time) from 1 to 7. This should effect the pax_t or total passenger time; in this case the number of flights is much higher than in groups 1 and 2 which means that the 219 passengers will show some clear behaviour change that can identify the relationship as Figure 6.6 demonstrates. In addition, x_ray_t is much lower than in groups 1 and 2, which gives more emphasis to the relationship between img_t and the output variables shown in Table 6.6.

Table 6.6 Group 3 brief detailed input output table

G3	*F/D*	*P/F*	*img_t*	*x_ray_t*	*av*	*disp_pax*	*pax_t*	*total_pax_no*	*cap*
16	100	219	1	0.5	100	10750.5	31.99	11244.59	0.96
17	100	219	2	0.5	100	10758	32.42	11255.84	0.96
18	100	219	3	0.5	100	10732	33.77	11248.93	0.95
19	100	219	4	0.5	100	10753.5	35.39	11293.81	0.95
20	100	219	5	0.5	100	10712.5	37.45	11283.08	0.95
21	100	219	6	0.5	100	10720.5	37.78	11295.64	0.95
22	100	219	7	0.5	100	10664.5	41.13	11291.52	0.94

Pax_t shows variance from 31 to 41 which correlates with the img_t variance from 1 to 7 as shown in Figure 6.6. There is a slight effect on the capacity ratio as it varies from 0.94 to

0.96. The number of disposed passengers changes in the same way but by decreasing in value, although there are some exceptions when img_t equals 6, 3 and 1. The chart shows the increment of the total passenger time with respect to img_t.

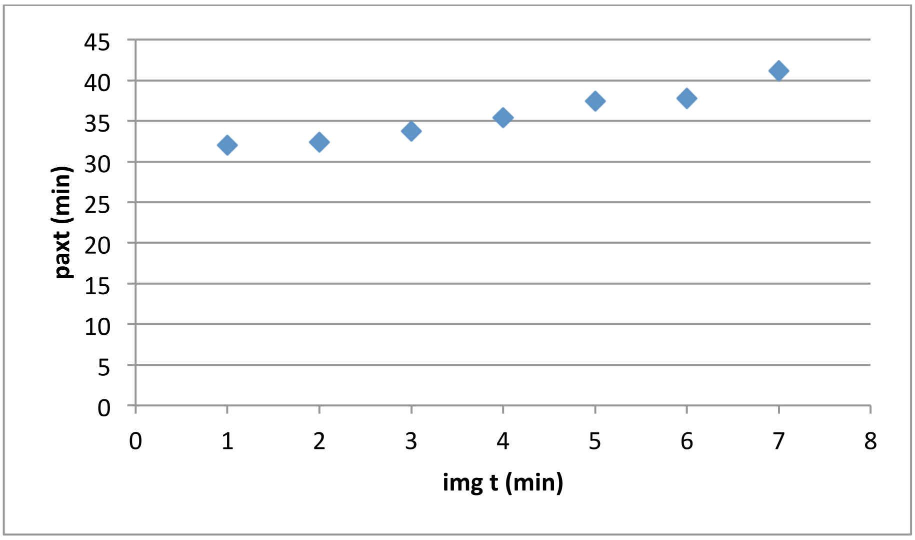


Figure 6.6 Group 3 the effect of immigration and passport check process time (img_t) on total passenger time (pax_t)

6.5 Description of Input Group 4

Group 4 has five trials prepared by fixing the four factors of F/D (number of flights per day) to 100, P/F (number of passengers per flight) to 219, img_t (immigration check time) to 1 and x_ray_t (time for customs and x-ray scanning) to 0.5 while changing the variable av (percentage of the available immigration staff) from 20 to 100. Contrary to the expected, pax_t did not respond to that change. The reason for this may be the low level of utilisation the terminal experienced by having both F/D (100) and P/F (219),which were quite low compared with the first trial, along with low time in immigration. X_ray_t was also found to be reasonable, not taking a high time for each passenger in this group. Table 6.7 shows stability in the four output variables disp_pax, pax_t, cap ratio and total_pax_no.

Table 6.7 Group 4 brief detailed input output table

G4	*F/D*	*P/F*	*img_t*	*x_ray_t*	*av*	*disp_pax*	*pax_t*	*total_pax_no*	*cap*
24	100	219	1	0.5	100	10750.5	31.99	11244.59	0.96
25	100	219	1	0.5	70	10803	33.74	11323.34	0.96
26	100	219	1	0.5	50	10749	32.15	11245.47	0.96
27	100	219	1	0.5	30	10764.5	32.79	11269.23	0.96
28	100	219	1	0.5	20	10746	31.70	11234.57	0.96

Pax_t can be plotted as a horizontal line with y value of 32 min plus or minus 1. This will bring us to increase img_t in the next group to criticise the behaviour of the system. Figure 6.7 below demonstrates the group 4 trials with pax_t and for the remaining four outputs nearly the same happens, as disp_pax has a value of 10746+0.5% (very low variance range) in the y axis, and total_pax_no has a value of 11234+0.3% (very low variance) and cap ratio is 0.96.

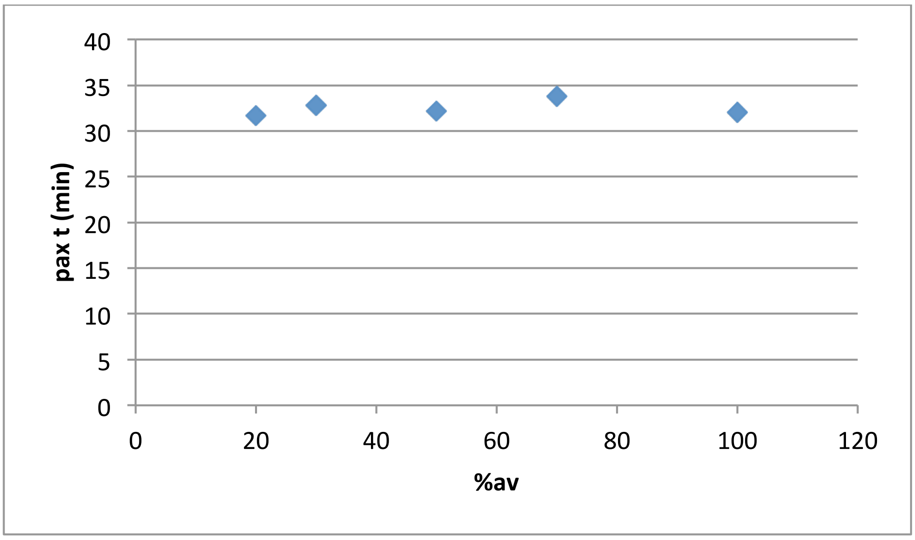


Figure 6.7 Group 4 the effect of available immigration staff ratio (av) on total passenger time (pax_t)

6.6 Description of Input Group 5

This group also has five trials which are made by fixing the four factors of F/D (number of flights per day) at 100, img_t (immigration check time) at 3, x_ray_t (time for customs and x-ray scanning) at 1.5 and av (percentage of the available immigration staff) at 100 while changing the variable P/F (number of passengers per flight) from 100 to 170. That ordinarily greatly effects the pax_time or total passenger time. Immigration check time or img_t value of 3 is quite good for such a process with the number of available staff and x_ray_t value of 1.5 is a bit high as it can lead to high levels of bottlenecks in customs, and security scanning and checking which adds a delay as is shown in pax_t column in Table 6.8.

Table 6.8 Group 5 brief detailed input output table

G5	*F/D*	*P/F*	*img_t*	*x_ray_t*	*av*	*disp_pax*	*pax_t*	*total_pax_no*	*cap*
29	100	100	3	1.5	100	4898.5	49.56	5247.19	0.93
30	100	120	3	1.5	100	5692.5	86.21	6419.29	0.88
31	100	140	3	1.5	100	6573	79.49	7372.81	0.89
32	100	160	3	1.5	100	6610	138.45	8245.76	0.80
33	100	170	3	1.5	100	7028	173.44	9120.69	0.77

This group illustrates great deal of impact of P/F clearly on all four-output aspects; as P/F changes from 100 to 170 the value of disp_pax varies between 4898 to 7028, while pax_t changes from 49.5 min to 173.4 min. On the other hand total_pax_no increased from 5247 to 9120, and finally cap ratio has decreased from 0.93 to 0.77 (see Figure 6.8).

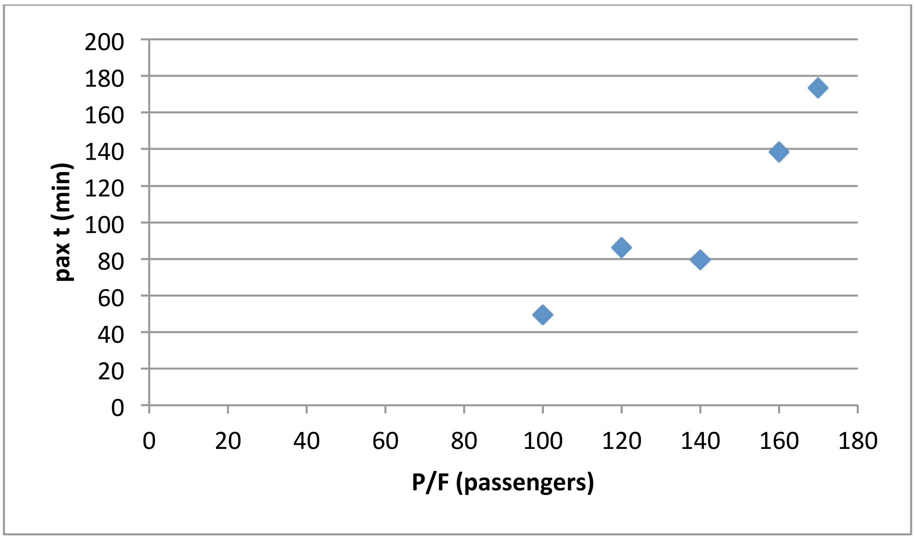


Figure 6.8 Group 5 the effect of number of passengers per flight (P/F) on total passenger time (pax_t)

6.7 Description of Input Group 6

The variable P/F (number of passengers per flight) is varied from 100 to 160 in this group where F/D (number of flights per day) is fixed at 100, img_t (immigration check time) at 1.5, x_ray_t (time for customs and x-ray scanning) at 1.5 and av (percentage of the available immigration staff) at 100. The influence shown on the four output elements is: disp_pax (number of disposed passengers from the airport terminal) increased from 4887 to 6765, pax_t (passengers total time spent in the terminal) increased from 53 to 149 min, total_pax_no (total number of passengers generated in the simulation) increased from 5265 to 8563, and cap ratio (capacity ratio of disposed passengers to total number of passengers) decreased from 92% to 79%, as shown in Table 6.9.

Table 6.9 Group 6 brief detailed input output table

G6	*F/D*	*P/F*	*img_t*	*x_ray_t*	*av*	*disp_pax*	*pax_t*	*total_pax_no*	*cap*
34	100	100	1.5	1.5	100	4887.5	53.59	5265.53	0.93
35	100	120	1.5	1.5	100	5706.5	69.96	6299.85	0.91
36	100	140	1.5	1.5	100	6411	81.58	7219.59	0.89
37	100	160	1.5	1.5	100	6765	149.38	8563.66	0.79

A slope equalling 1.6 (angle 58°) has been calculated between the two points P1(100, 53.59), P2(160, 149.38) where P=(P/F, pax_t). Figure 6.9 shows a good representation of the system behaviour as it is needed to be entered into the Nero fuzzy logic analyser. The same is expected to be illustrated easily for the remaining variables where slope disp_pax is found to be 31.3 (angle 88.1°) between the points P1(100, 4887.5), P2(160, 6765) while total_pax_no slope is measured to be 55 (angle 89°) between P1(100, 5265.53), P2(160, 8563.66) and lastly cap slope equals -0.00233 (angle -0.1336°) between P1(100, 0.92), P2(160,0.78).

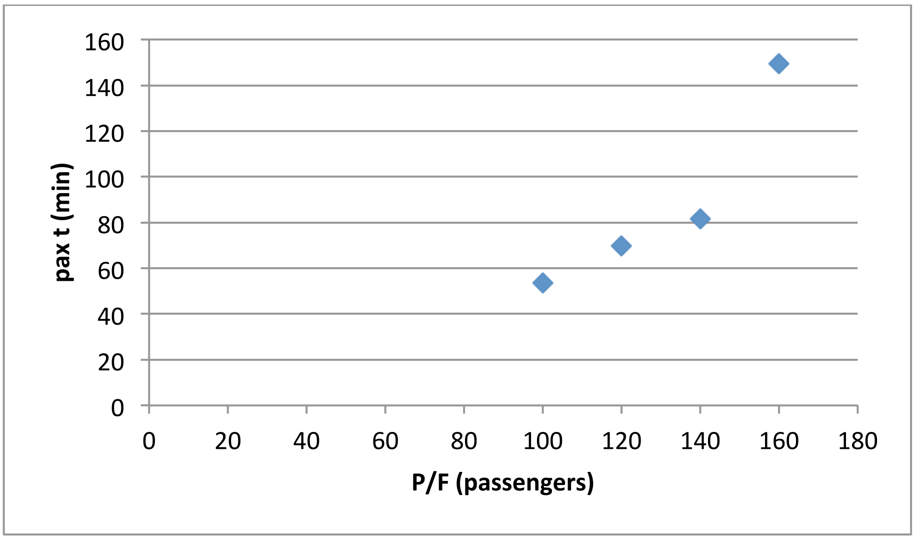


Figure 6.9 Group 7 the effect of number of passengers per flight (P/F) on total passenger time (pax_t)

6.8 Description of Input Group 7

By looking into this group, it can be seen that a different response occurs, as only pax_t is spotted to have a high influence, as it increases accordingly with the increment of img_t. Here img_t (immigration check time) is varied from 1 to 6 min where F/D (number of flights per day) is fixed at 134, P/F (number of passengers per flight) at 219, x_ray_t (time for customs and x-ray scanning) at 0.5 and av (percentage of the available immigration staff) at 100 (see Table 6.10).

Table 6.10 Group 7 brief detailed input output table

G7	*F/D*	*P/F*	*img_t*	*x_ray_t*	*av*	*disp_pax*	*pax_t*	*total_pax_no*	*cap*
38	134	219	6	0.5	100	14062.5	54.62	15194.41	0.93
39	134	219	5	0.5	100	14348.5	43.62	15243.37	0.94
40	134	219	4	0.5	100	14330	38.50	15117.94	0.95
41	134	219	3	0.5	100	14229	39.17	15033.51	0.95
42	134	219	2	0.5	100	14434.5	35.96	15169.41	0.95
43	134	219	1	0.5	100	14324.5	33.83	15017.2	0.95

Results shows disp_pax approximately varied by 2.6% as it changed from 14062 to 14434 if img_t (immigration check time) changed from 1 to 6 min, 1.51% for total_pax_no (total number of passengers generated in the simulation), 3.07% for cap (capacity ratio of disposed passengers to total number of passengers) while there was a 61.47% difference calculated between max and min value of pax_t (see Figure 6.10).

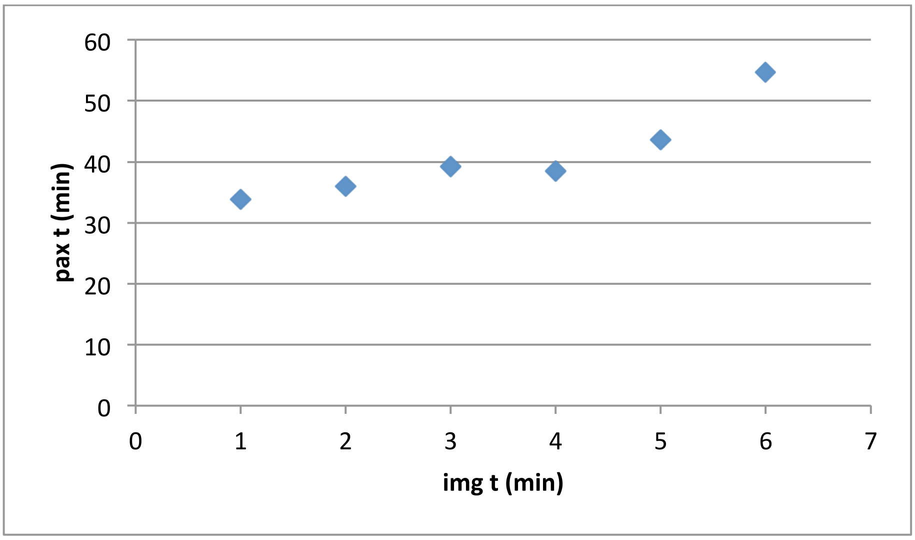


Figure 6.10 Group 7 the effect of immigration and passport check process time (img_t) on total passenger time (pax_t)

6.9 Description of Input Group 8

This group has four trials prepared by fixing the four factors of F/D (number of flights per day) at 160, P/F (number of passengers per flight) at 219, x_ray_t (time for customs and x-ray scanning) at 0.5 and av (percentage of the available immigration staff) at 100 while changing the variable img_t (immigration check time) from 1 to 4. (see Table 6.11)

Table 6.11 Group 8 brief detailed input output table

G8	*F/D*	*P/F*	*img_t*	*x_ray_t*	*av*	*disp_pax*	*pax_t*	*total_pax_no*	*cap*
44	160	219	4	0.5	100	16870	46.73	18017.77	0.94
45	160	219	3	0.5	100	16936	48.79	18133.64	0.933
46	160	219	2	0.5	100	17081.5	38.47	18023.57	0.95
47	160	219	1	0.5	100	16894.5	45.42	18016.75	0.941

By looking at Table 6.11 it can be said there is no clear influence on the four performance variables, as can be caused by low utilisation in this group. By changing the variable img_t (immigration check time) from 1 to 4, it was found that disp_pax oscillates between 16870 and 17081 (1.25% difference) , pax_t fluctuates in the range of 38.47 - 48.79 minutes with the difference estimated to be 27% at the most, total_pax_no varies slightly between 18016 and 18133 (with approximate slope of 0.34), and lastly the cap variable is almost unchanged in this group with an angle of -0.02698° (see Figure 6.11).

Table 6. 12 some details related to group 8 outputs

	disp_pax	*pax_t*	*total_pax_no*	*cap*
%	1.25%	26.83%	0.65%	1.48%
slope	-8.16	0.4372	0.34	-0.00047
Angle	-83.02	23.6165	18.7780	-0.02698

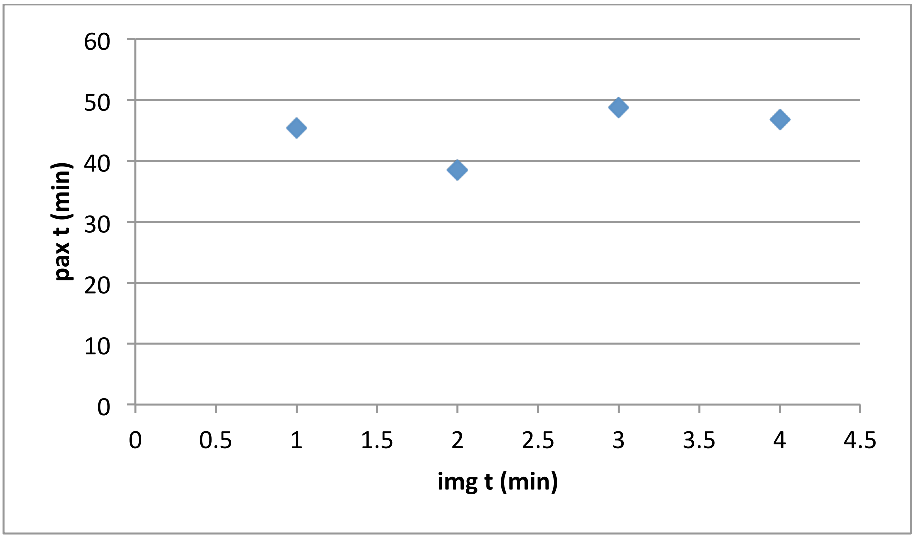


Figure 6.11 Group 8 the effect of immigration and passport check process time (img_t) on total passenger time (pax_t)

6.10 Description of Input Group 9

Group nine contains six simulated trials with img_t (immigration check time) variable changing from 1 to 6 minutes while the other four factors are unchanging. F/D (number of flights per day) is set at 29, P/F (number of passengers per flight) at 219, x_ray_t (time for customs and x-ray scanning) at 0.5 and av (percentage of the available immigration staff) at 100. As in these trials F/D (number of flights per day) is below the last group, the same behaviour is expected out of plotting pax_t. The details of the inputs and outputs are below listed in Table 6.13.

Table 6.13 Group 9 brief detailed input output table

G9	F/D	P/F	img_t	x_ray_t	av	disp_pax	pax_t	total_pax_no	cap
48	29	219	1	0.5	100	3188.5	28.45	3298.07	0.97
49	29	219	2	0.5	100	3190	29.54	3300.17	0.97
50	29	219	3	0.5	100	3186.5	30.45	3296.48	0.97
51	29	219	4	0.5	100	3186.5	31.49	3296.55	0.97
52	29	219	5	0.5	100	3181	32.57	3293.12	0.97
53	29	219	6	0.5	100	3181	33.41	3293.39	0.97

The predicted room for change is low (below 0.25%) for all factors apart from pax_t (passengers total time spent in the terminal) which shows 17.5% difference at the most. The trials produce a linear graph steadily increasing as shown in Figure 6.12.

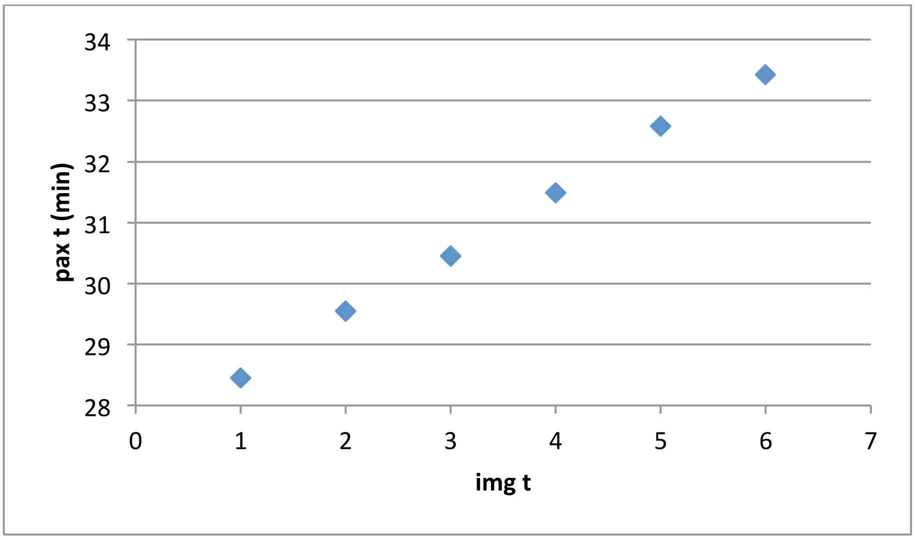


Figure 6.12 Group 9 the effect of immigration and passport check process time (img_t) on total passenger time (pax_t)

6.11 Description of Input Group 10

This group will study the effect of x_ray_t on the total pax_t and disposed passenger number and ratio to total arrived passengers. Six trials are made with a low number of planes per day (F/D of 14), and the average rate of passengers per flight set at 200, and low immigration check time of 1min and 100% percentage of the available immigration staff. X_ray_t varies from 1 to 20 minutes as listed in Table 6.14.

Table 6.14 Group 10 brief detailed input output table

G10	F/D	P/F	img_t	x_ray_t	av	disp_pax	pax_t	total_pax_no	cap
54	14	200	1	20	100	407.5	557.72	1767.02	0.23
55	14	200	1	15	100	606.5	461.81	1686.77	0.36
56	14	200	1	10	100	883	410.25	1729.28	0.51
57	14	200	1	5	100	1116.5	213.4	1550.91	0.72
58	14	200	1	3	100	1361	96.58	1555.26	0.88
59	14	200	1	1	100	1407.5	40.32	1507.5	0.93

As has been observed, passenger total time is changed sharply in this group with more than 10 times ratio between min and max value. It is found to be more sharply increasing between 1 and 10 min (see Figure 6.13). On the other hand, the total number of passengers remains steady with only 17% ratio of change. Capacity ratio is dropped from 93% to 23% during these six trials.

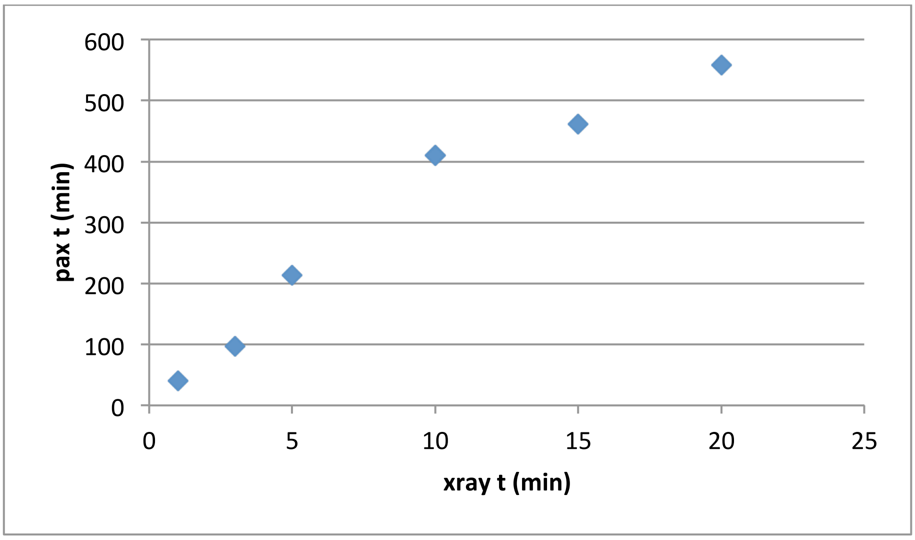


Figure 6.13 Group 10 the effect of x-ray and customs check process time (x_ray_t) on total passenger time (pax_t)

6.12 Description of Input Group 11

This group of trials focuses on the effect of changing av% between 30 and 100 in four trials. The other four variables remain unchanged as F/D (number of flights per day) is fixed at 29, P/F (number of passengers per flight) is set at 219, img_t (immigration check time) is set at 1 and x_ray_t (time for customs and x-ray scanning) is set at 0.5 min. The low value of F/D, x_ray_t and img_t can lead to have a low level of utilisation, and might not show a great deal of influence on output factors as shown in Table 6.15.

Table 6.15 Group 11 brief detailed input output table

G11	F/D	P/F	img_t	x_ray_t	av	disp_pax	pax_t	total_pax_no	cap
60	29	219	1	0.5	100	17544.3	28.44	17653.86	0.99
61	29	219	1	0.5	50	17543.85	28.53	17653.47	0.99
62	29	219	1	0.5	30	17543.45	28.71	17653	0.99
63	29	219	1	0.5	70	17543.95	28.47	17653.54	0.99

Almost no change is observed on the four output factors, shown in Table 6.15, where it can be seen that pax_t equals 28 min (no significant difference) for approximately 17653 daily arriving passengers distributed over 29 flights. Capacity ratio of disposed passengers to overall arrived passengers is estimated to be at least 99%. The pax_t will be plotted as a horizontal parallel line with approximate distance of 28 min from x-axis as shown in Figure 6.14.

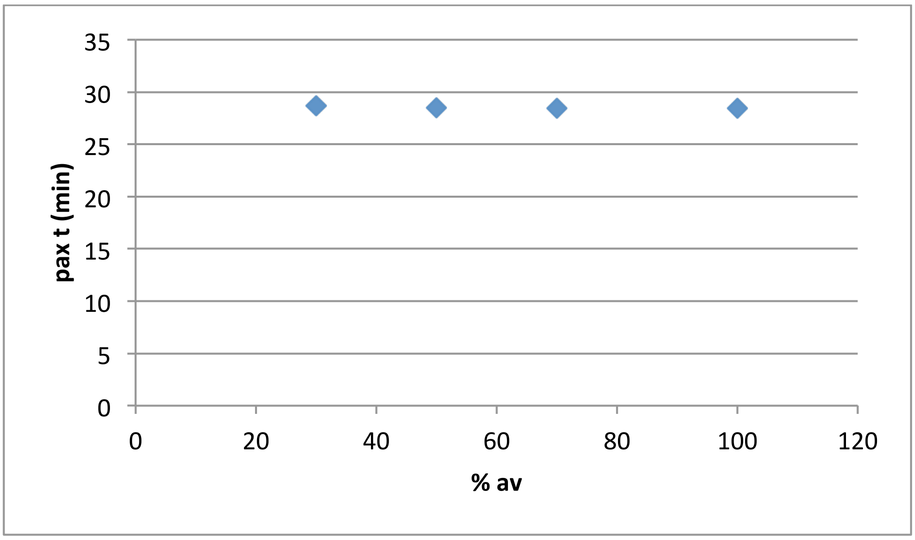


Figure 6.14 The effect of available immigration staff ratio (av) on total passenger time (pax_t)

6.13 Description of Input Group 12

X_ray_t (time for customs and x-ray scanning) is varied in this group from 1 to 2.5 min as it is expected to create a bottleneck and a high level of delays, but without affecting the number of passenger arrived or disposed. Four trials are prepared with a low number of planes per day (F/D of 29), average rate of passengers per flight of 219, low immigration check time of 1 min and 100% percent of the available immigration staff. X_ray_t varies from 1 to 2.5 minutes as demonstrated in Table 6.16.

Table 6.16 Group 12 brief detailed input output table

G12	*F/D*	*P/F*	*img_t*	*x_ray_t*	*av*	*disp_pax*	*pax_t*	*total_pax_no*	*cap*
64	29	219	1	2.5	100	16943.95	242.61	18040.37	0.94
65	29	219	1	2	100	17342.75	105.65	17811.43	0.97
66	29	219	1	1.5	100	17443.55	67.70	17739.6	0.98
67	29	219	1	1	100	17488.3	44.60	17686.39	0.99

A great deal of variation (more than 400%) is measured on pax_t (passengers total time spent in the terminal) with even minor alterations of the variable of x_ray_t, with a clear sharp increment found between 2 and 2.5 min (see Figure 6.15). The number of disposed passengers from the airport terminal (disp_pax) remains around 1700 with a small variance (3% difference). The total number of passengers generated in the simulation (total_pax_no) has steady behaviour, varying between 17686 and 18040 (2% difference). Capacity ratio of disposed passengers to total number of passengers (cap) similarly has steady behaviour and changes slightly from 94% to 99%.

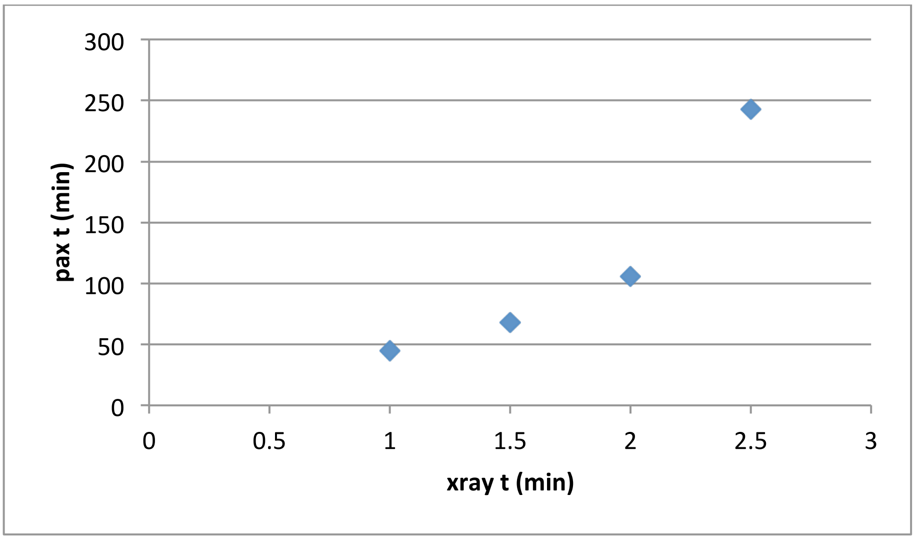


Figure 6.15 Group 12 the effect of x-ray and customs check process time (x_ray_t) on total passenger time (pax_t)

6.14 Description of Input Group 13

Group 13 has eight trials, carried out by assigning F/D (number of flights per day) to 40, P/F (number of passengers per flight) to 200, img_t (immigration check time) to 4 and x_ray_t (time for customs and x-ray scanning) to 1 while changing the variable av (percentage of the available immigration staff) from 30 to 100. It is predicted usually that pax_t may not respond to that change. This can be because of the low level of utilisation the terminal experiences by having both F/D (40) and P/F (200) quite low. The below table shows steadiness in the four output variables disp_pax, pax_t, total_pax_no and cap (see Table 6.17).

Table 6.17 Group 13 brief detailed input output table

G13	*F/D*	*P/F*	*img_t*	*x_ray_t*	*av*	*disp_pax*	*pax_t*	*total_pax_no*	*cap*
68	40	200	4	1	30	3938	48.46	4202.8	0.93
69	40	200	4	1	40	3940.5	44.77	4183.35	0.94
70	40	200	4	1	50	3917.5	46.13	4167.58	0.94
71	40	200	4	1	60	3942	56.67	4254.1	0.93
72	40	200	4	1	70	3916	44.44	4157.19	0.94
73	40	200	4	1	80	3941	47.72	4200.11	0.94
74	40	200	4	1	90	3916.5	47.32	4175.24	0.94
75	40	200	4	1	100	3936.5	44.76	4179.25	0.94

There is almost no change in the four output factors, as witnessed in the previous table, and that can be understood as pax_t equals 44 - 56 min (no significant variation) for approximately 4200 daily arrived passenger ratio. The capacity ratio of disposed passengers to overall arrived passengers is estimated to be at least 93% - see Figure 6.16.

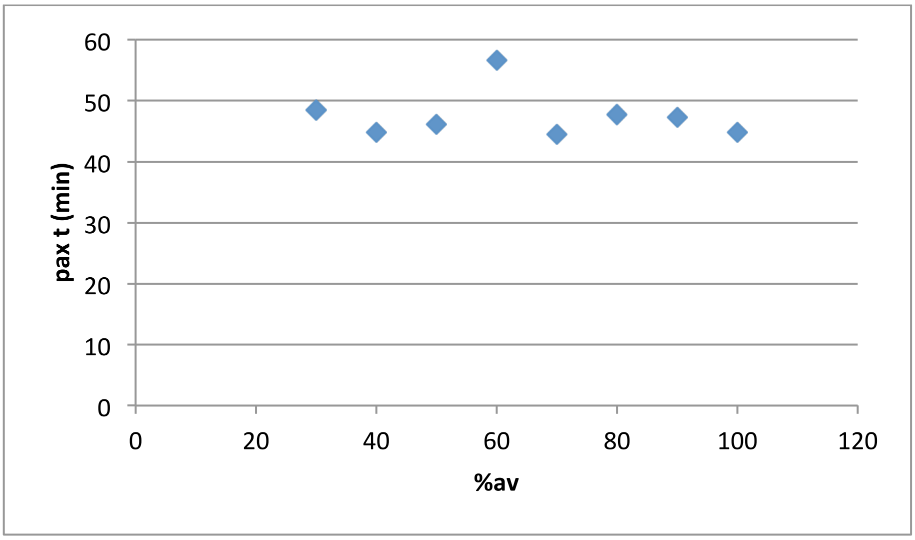


Figure 6.16 Group 13 the effect of available immigration staff ratio (av) on total passenger time (pax_t)

6.15 Description of Input Group 14

X_ray_t (time for customs and x-ray scanning) is changed in this group from 1 to 10 min as it is likely to create a bottleneck and a high level of suspension of activity, but without a great effect on number of passenger arrived or disposed. Five trials were arranged with a low number of planes per day (F/D of 20), lower than average rate of passengers per flight (P/F 120), low immigration check time of 1 min and 100% percentage of the available immigration staff. X_ray_t varies from 1 to 10 minutes as expressed in Table 6.18.

Table 6.18 Group 14 brief detailed input output table

G14	*F/D*	*P/F*	*img_t*	*x_ray_t*	*av*	*disp_pax*	*pax_t*	*total_pax_no*	*cap*
76	20	120	2.5	1	100	3630.5	31.99	3690.5	0.98
77	20	120	2.5	3	100	3602.9	68.23	3718.82	0.97
78	20	120	2.5	5	100	3562.1	124.06	3770.12	0.94
79	20	120	2.5	7	100	3383.6	224.42	3766.17	0.90
80	20	120	2.5	10	100	2673.5	723.96	4062.94	0.66

A huge variation is measured in pax_t (passengers' total time spent in the terminal) by alteration of the variable of x_ray_t, shown by the clear sharp increment found between 7 and 10 min (see Figure 6.17). The number of disposed passengers from airport terminal (disp_pax) changes between 2673 to around 3630. The total number of passengers generated in the simulation (total_pax_no) varies between 3690 and 4062. The capacity ratio of disposed passengers to total number of passengers (cap) changes slightly between 65% and 98%.

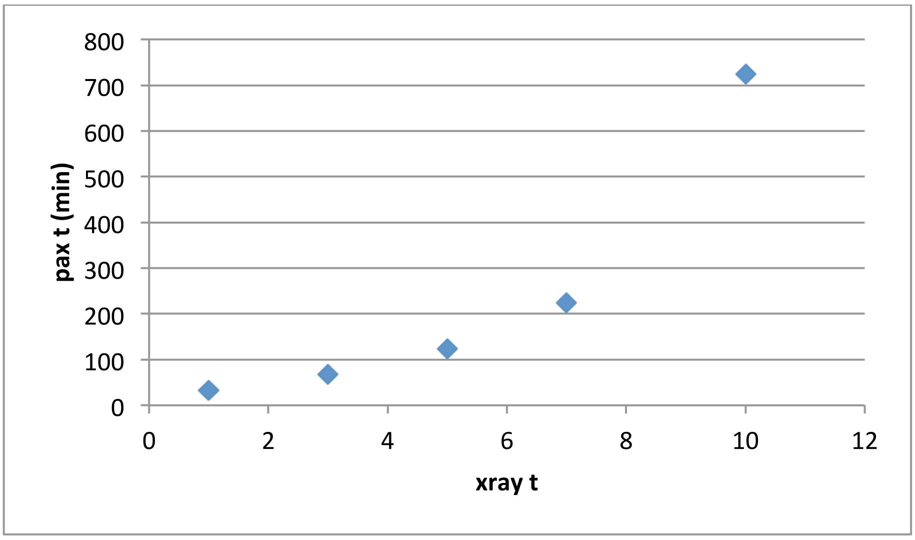


Figure 6.17 Group 14 the effect of x-ray and customs check process time (x_ray_t) on total passenger time (pax_t)

6.16 Description of Input Group15

In this group, five trials are carried out by fixing the four factors of F/D (number of flights per day) to 25, P/F (number of passengers per flight) to 125, x_ray_t (time for customs and x-ray scanning) to 1.5 and av (percentage of the available immigration staff) to 100 while changing the variable img_t (immigration check time) from 1 to 10. This should affect the pax_time or (total passenger time). See Table 6.19.

Table 6.19 Group 15 brief detailed input output table

G15	F/D	P/F	img_t	x_ray_t	av	disp_pax	pax_t	total_pax_no	cap
81	25	125	1	1.5	100	4712.3	39.30	4791.03	0.98
82	25	125	3	1.5	100	4708.9	41.35	4791.59	0.98
83	25	125	5	1.5	100	4707	43.35	4794.16	0.98
84	25	125	7	1.5	100	4704.3	45.32	4796.51	0.98
85	25	125	10	1.5	100	4700.5	48.22	4800.04	0.98

Pax_t shows variance from 39 to 48; this is linked with the img_t variance from 1 to 10 shown in Figure 6.18. There is no effect on the capacity ratio as it stays at 0.98. The disposed number of passengers has an almost constant value as it changes from 4791 to 4800. The chart in Figure 6.18 shows a slight increment in the total passenger time with respect to img_t.

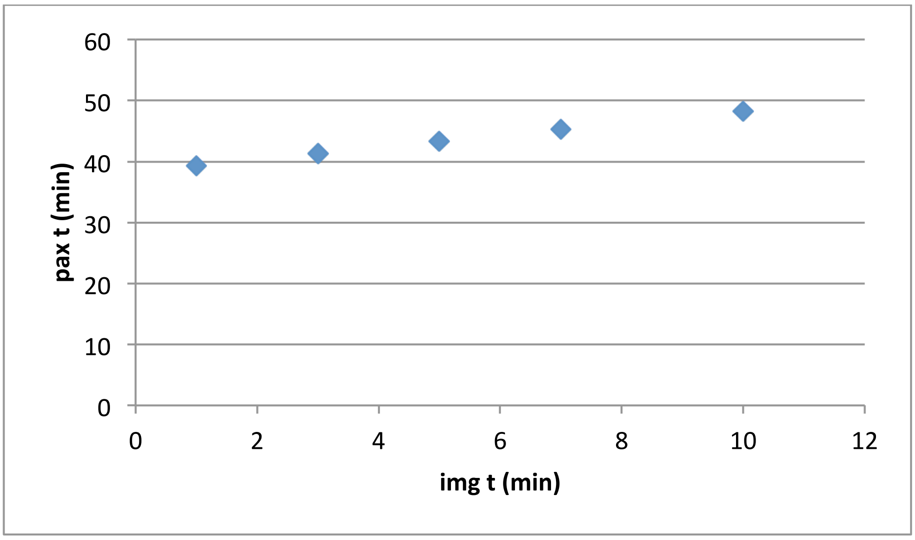


Figure 6.18 Group 15 the effect of immigration and passport check process time (img_t) on total passenger time (pax_t)

6.17 Description of Input Group 16

X-ray t (time for customs and x-ray scanning) is altered in this group from 0.5 to 7 min as it is liable to produce a bottleneck and a high level of postponement, but without that great effect on the number of passengers arriving or disposed. Eight trials are arranged with a low range of planes per day (F/D of 25), lower than average rate of passengers per flight (P/F 125), immigration check time of 2 min and 100% percentage of the available immigration staff. X_ray_t varies from 1 to 10 min as expressed in Table 6.20.

Table 6.20 Group 16 brief detailed input output table

G16	F/D	P/F	img_t	x_ray_t	av	disp_pax	pax_t	total_pax_no	cap
86	25	125	2	7	100	3969.8	421.22	4964.13	0.80
87	25	125	2	6	100	4301.5	321.26	5033.91	0.85
88	25	125	2	5	100	4367.5	278.09	5003.57	0.87
89	25	125	2	4	100	4618.3	115.33	4870.52	0.95
90	25	125	2	3	100	4665	75.49	4827.84	0.97
91	25	125	2	2	100	4693.2	50.39	4802.86	0.98
92	25	125	2	1	100	4724.8	32.04	4787.5	0.99
93	25	125	2	0.5	100	4725.5	23.97	4788	0.99

A large difference is measured in pax_t (passengers total time spent in the terminal) from 23 min to 421 min by amendment of the variable of x_ray_t, as seen by the clear quick increment found after 4 min, shown in Figure 6.19. The number of disposed passengers from the airport terminal (disp_pax) changes from 3969 to 4725. The total number of passengers generated in the simulation (total_pax_no) has steady behaviour changing from 4788 to 5033 (5% difference). The capacity ratio of disposed passengers to total number of passengers (cap) varies between 79% and 99%.

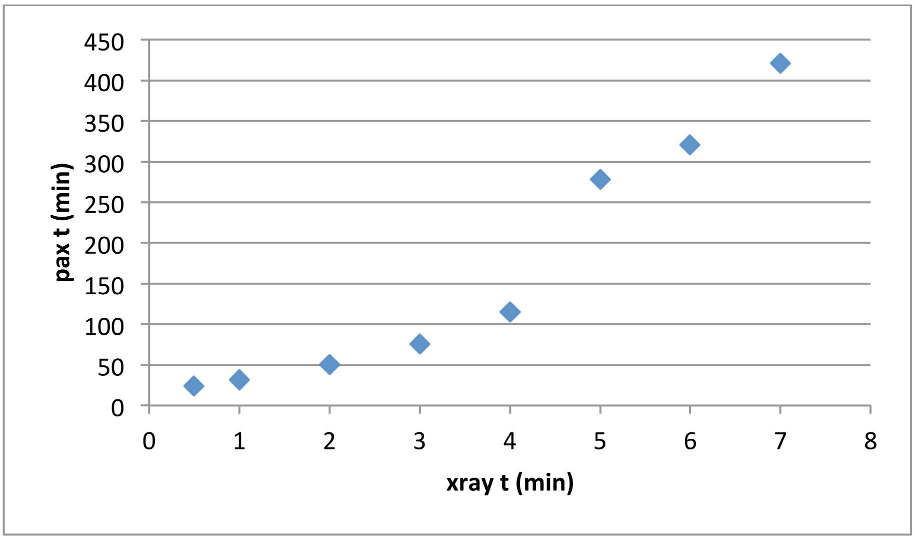


Figure 6.19 Group 16 the effect of x-ray and customs check process time (x_ray_t) on total passenger time (pax_t)

6.18 Description of Input Group 17

The variable P/F (number of passengers per flight) is changed from 100 to 600 in this group where F/D (number of flights per day) is fixed at 100, img_t (immigration check time) at 4 min, x_ray_t (time for customs and x-ray scanning) at 1min and av (percentage of the available immigration staff) at 100. The influence on the four output elements is as follows:

disp_pax (number of disposed passengers from airport terminal) increased from 1996 to 8411; pax_t (passengers total time spent in the terminal) increased from 30 to 151 min; total_pax_no (total number of passengers generated in the simulation) increased from 2075 to 10599, and cap (capacity ratio of disposed passengers to total number of passengers) decreased from 96% to 79%, as shown in Table 6.21.

Table 6.21 Group 17 brief detailed input output table

G17	*F/D*	*P/F*	*img_t*	*x_ray_t*	*av*	*disp_pax*	*pax_t*	*total_pax_no*	*cap*
94	40	100	4	1	100	1996	30.93	2075.35	0.96
95	40	200	4	1	100	3936.5	44.76	4179.25	0.94
96	40	300	4	1	100	5793	74.70	6418.64	0.90
97	40	400	4	1	100	7043.5	122.92	8464.47	0.83
98	40	500	4	1	100	8411	151.2	10599.48	0.79

A slope equal to 0.3 (angle 16.73°) is calculated between the two points P1(100, 30.9346), P2(500, 151.2) where P=(P/F, pax_t). Figure 6.20 shows good representation of the system behaviour as it is needed to be entered into the Nero fuzzy logic analyser. The same is expected to be illustrated easily for the remaining variables where slope disp_pax is found to be 31.3 (angle 88.1°) between the points P1(100, 1996), P2(500, 8411) while total_pax_no slope is measured to be 55 (angle 89°) between P1(100, 2075.35), P2(160, 10599.48) and lastly cap slope equals -0.00233 (angle - 0.1336°) between P1(100, 0.96), P2(160, 0.79).

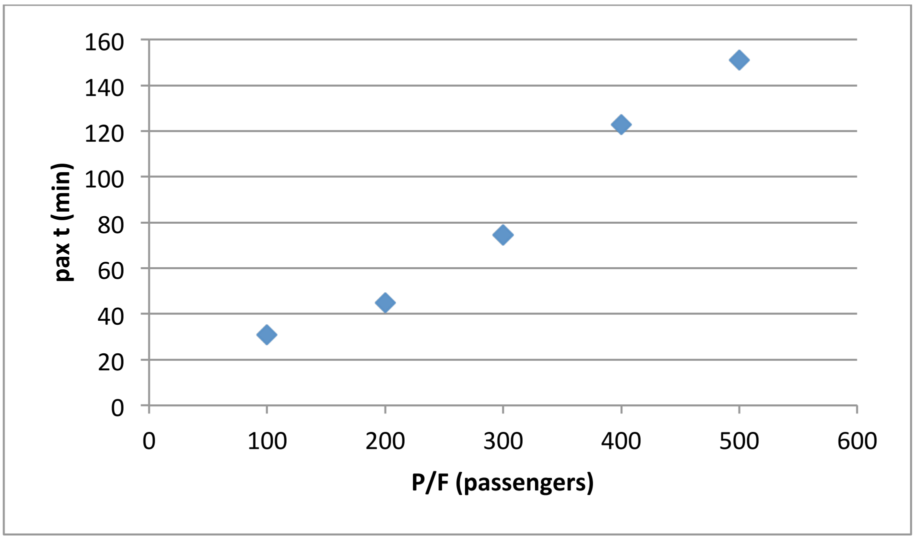


Figure 6.20 Group 17 the effect of number of passengers per flight (P/F) on total passenger time (pax_t)

6.19 Description of Input Group 18

This group has eleven trials prepared by fixing the four factors of F/D (number of flights per day) at 50, img_t (immigration check time) at 3, x_ray_t (time for customs and x-ray scanning) to 1.5 and av (percentage of the available immigration staff) to 100 while changing the variable P/F (number of passengers per flight) from 100 to 300. That ordinarily greatly effects the pax_time or total passenger time. Immigration check time or img_t value of 3 is quite average for such a process with the number of available staff and x_ray_t value of 1.5 is slightly over average as it can lead to long queues in customs, and security scanning and checking which keeps more work in process (WIP). For that reason a low capacity might be expected add a delay as is shown in pax_t column in the Table 6.22.

Table 6.22 Group 18 brief detailed input output table

G18	*F/D*	*P/F*	*img_t*	*x_ray_t*	*av*	*disp_pax*	*pax_t*	*total_pax_no*	*cap*
99	50	100	3	1.5	100	2476	38.32	2607.35	0.95
100	50	120	3	1.5	100	2959.5	42.53	3135.14	0.94
101	50	140	3	1.5	100	3440.5	53.15	3699.32	0.93
102	50	160	3	1.5	100	3872.5	59.02	4201.18	0.92
103	50	180	3	1.5	100	4385.5	63.89	4785.81	0.92
104	50	200	3	1.5	100	4833.5	80.37	5395.23	0.90
105	50	220	3	1.5	100	5081	101.39	5866.91	0.87
106	50	240	3	1.5	100	5726.5	103.87	6599.91	0.87
107	50	260	3	1.5	100	5438.5	125.45	6663.83	0.82
108	50	300	3	1.5	100	6078	187.17	8136.39	0.75

Group 18 demonstrates clearly a high influence of P/F on all four output factors - as P/F changes from 100 to 300, the value of disp_pax varies dramatically between 2476 and 6078, while pax_t changes from 38.3 min to 187.1 min. On the other hand total_pax_no increased radically from 2607 to 8136 and lastly cap has decreased from 0.95 to 0.75 (see Figure 6.21).

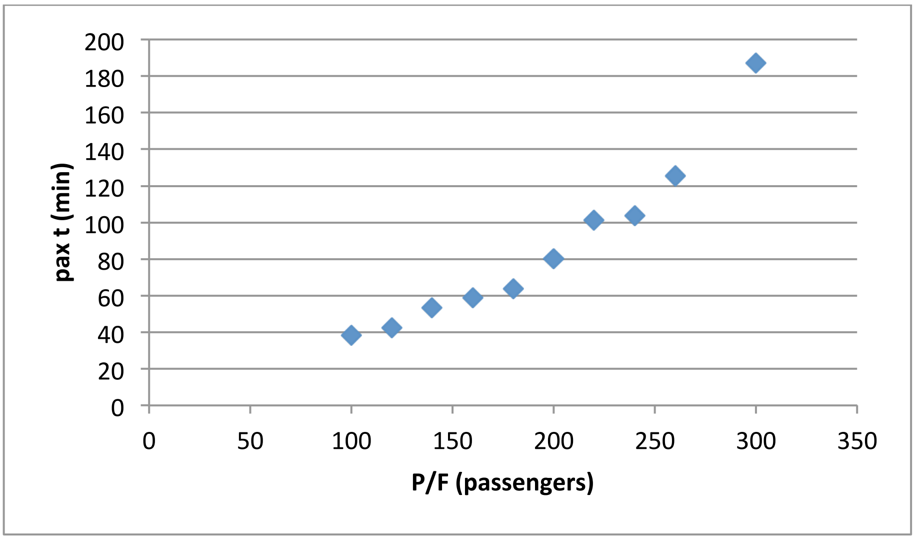


Figure 6.21 Group 18 the effect of number of passengers per flight (P/F) on total passenger time (pax_t)

6.20 Description of Input Group 19

Four trials were prepared in this group by fixing the four factors of P/F (number of passengers per flight) at 300, img_t (immigration check time) at 3, x_ray_t (time for customs and x-ray scanning) at 1.5 and av (percentage of the available immigration staff) at 100 while changing the variable F/D (number of flights per day) from 10 to 40. That should effects significantly the pax_time or (total passenger time) as every plane contains an average of 300 passengers in this group. Immigration check time or img_t value of 3 is quite average for such a process with the number of available staff, and x_ray_t value of 1.5 is slightly over the standard as it can lead to some delays in customs, and security scanning and checking, which keeps more work in process. For that reason a decrease in capacity might be expected to add a delay in pax_t column. See Table 6.23.

Table 6.23 Group 19 brief detailed input output table

G19	*F/D*	*P/F*	*img_t*	*x_ray_t*	*av*	*disp_pax*	*pax_t*	*total_pax_no*	*cap*
109	40	300	3	1.5	100	5322	146.77	6561.65	0.81
110	30	300	3	1.5	100	4310.5	131.35	5132.92	0.84
111	20	300	3	1.5	100	2885	105.78	3329.94	0.87
112	10	300	3	1.5	100	1505.5	73.73	1656.3	0.91

Obvious impact of F/D clearly on all four-output factors as F/D decreases from 40 to 10 the value of disp_pax increases dramatically from 5322 to 1505, while pax_t changes from 146.7 min to 73.7 min, on the other hand total_pax_no decreased radically from 6561 to 1656 and lastly cap has increased from 0.81 to 0.91 (see Figure 6.22).

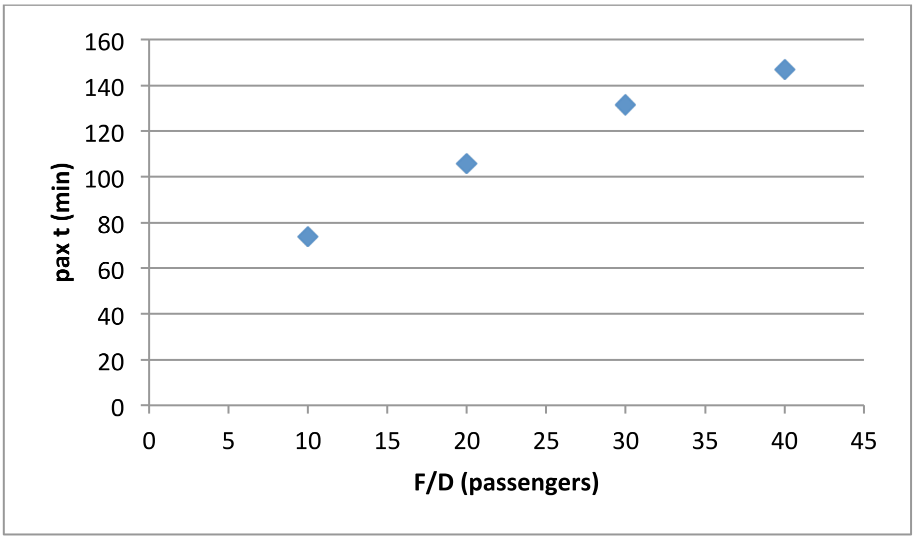


Figure 6.22 Group 19 the effect of number of flights arrived to the terminal per day (F/D) on total passenger time (pax_t)

6.21 Description of Input Group 20

Group 20 has five trials arranged by setting the four factors of P/F (number of passengers per flight) to 300, img_t (immigration check time) to 5, x_ray_t (time for customs and x-ray scanning) to 1.5 and av (percentage of the available immigration staff) to 100 while changing the variable F/D (number of flights per day) from 10 to 50. That should greatly influence the pax_time, or total passenger time, as every plane contains an average of 300 passengers in this group. Immigration check time or img_t value of 5 is quite high for such a process (can be estimated for eye-scanning scenario) with the existing number of staff , and the x_ray_t of 1.5 is a little higher as it can lead to noticeable delays in customs, and security scanning and checking, which leads to more work in process (WIP entities). As a consequence, a decrease in capacity might be expected to add more waiting to pax_t column as shown Table 6.24.

Table 6.24 Group 20 brief detailed input output table

G20	F/D	P/F	img_t	x_ray_t	av	disp_pax	pax_t	total_pax_no	cap
113	10	300	5	1.5	100	1504	75.99	1657.75	0.91
114	20	300	5	1.5	100	2921	98.18	3329.29	0.88
115	30	300	5	1.5	100	4142	91.34	4731.55	0.88
116	40	300	5	1.5	100	5355	127.59	6436.63	0.83
117	50	300	5	1.5	100	6049	220.27	8441.96	0.72

The influence of F/D is noticeable on all four output factors: as F/D increases from 10 to 50, the value of disp_pax increases dramatically from 1504 to 6049, while pax_t changes from 75.99 min to 220.27 min; on the other hand total_pax_no increases radically from 1657 to 8441 and lastly cap has decreased from 0.91 to 0.71 (see Figure 6.23).

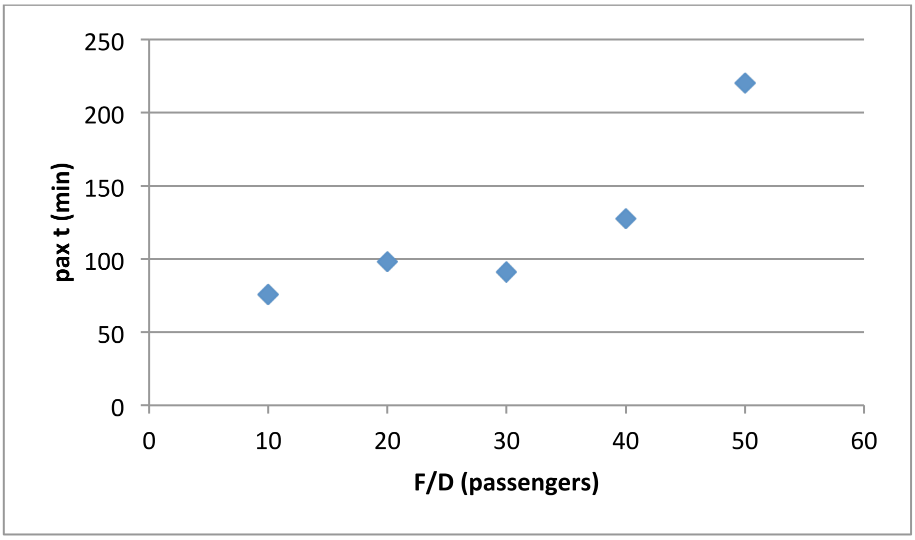


Figure 6.23 Group 20 the effect of number of flights arrived to the terminal per day (F/D) on total passenger time (pax_t)

6.22 Description of Input Group 21

This group of trials focuses on the effect of changing av% between 30 and 100 in four trials. The other four variables remain unchanged as F/D (number of flights per day) is fixed at 150, P/F (number of passengers per flight) set to 130, img_t (immigration check time) set to 2 and x_ray_t (time for customs and x-ray scanning) set to 1 min. The low value of img_t can mean a low level of utilisation and might not show a change in the output factors. See Table 6.25.

Table 6.25 Group 21 brief detailed input output table

G21	*F/D*	*P/F*	*img_t*	*x_ray_t*	*av*	*disp_pax*	*pax_t*	*total_pax_no*	*cap*
118	150	130	2	1	100	9293.5	70.61	10280.12	0.90
119	150	130	2	1	90	9146.5	69.61	10119.2	0.90
120	150	130	2	1	50	9282.5	76.62	10335.84	0.90
121	150	130	2	1	30	9082.5	72.12	10116.57	0.90

More or less no change of the four output factors is observed in the prior table and can be seen as pax_t equals 70 - 72 min (no significant difference) for approximate 19,500 daily arriving passengers distributed over 150 flights. Capacity ratio of disposed passengers to overall arrived passengers is estimated to be at least 89.7%. The pax_t will be plotted as an estimated horizontal parallel line with a gap of 70 min from the x-axis (see Figure 6.24).

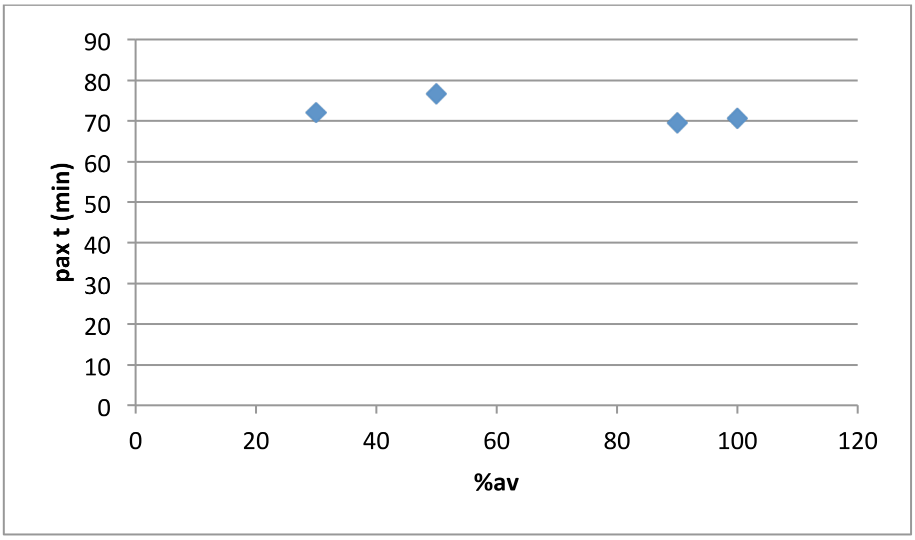


Figure 6.24 The effect of available immigration staff ratio (av) on total passenger time (pax_t)

6.23 Description of Input Group 22

Group 22 has five trials centred on the effect of changing av% between 30 and 100 in four trials. The other four variables are fixed as F/D (number of flights per day) is fixed at 100, P/F (number of passengers per flight) is set to 240, img_t (immigration check time) is set to 4 and x_ray_t (time for customs and x-ray scanning) is set to 0.5 min. The low rate of passengers per day can mean a low level of utilisation and might not show a change in the output factors (see Table 6.26).

Table 6.26 Group 22 brief detailed input output table

G22	*F/D*	*P/F*	*img_t*	*x_ray_t*	*av*	*disp_pax*	*pax_t*	*total_pax_no*	*cap*
122	100	240	4	0.5	100	11766	41.48	12461.28	0.94
123	100	240	4	0.5	90	11782.5	39.93	12451.34	0.95
124	100	240	4	0.5	75	11770.5	37.41	12396.68	0.95
125	100	240	4	0.5	50	11532.5	47.16	12324.4	0.94
126	100	240	4	0.5	30	10144	151.13	12793.49	0.79

A high change among the output factors is observed in the above table when the value of av% is very low (between 30-50), as pax_t varies between 37 - 151 min (instant sharp increase between 30-50) for approximately 24,000 daily arriving passengers distributed over 100 flights. The capacity ratio of disposed passengers to overall arrived passengers is estimated to be between 79% and 94%. The pax_t will be plotted with a highest point of 151 min when av% equals 30% (see Figure 6.25).

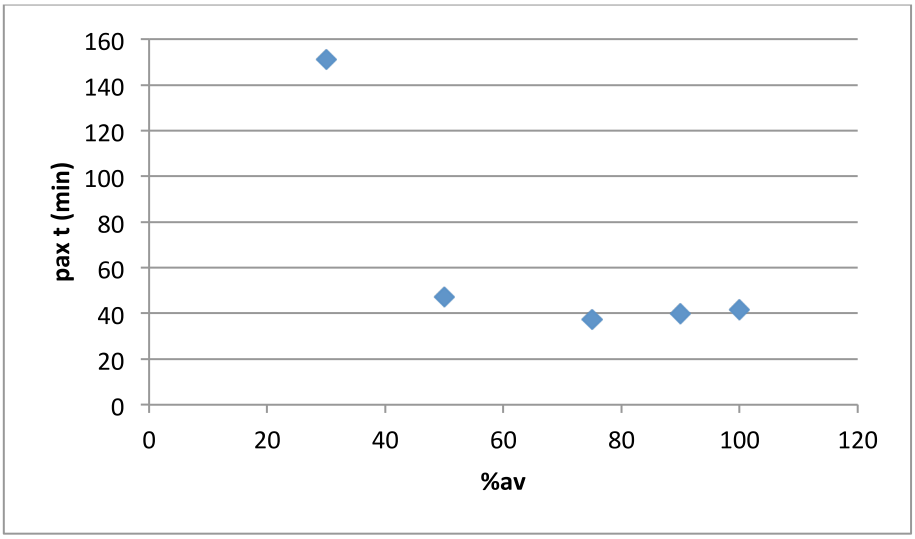


Figure 6.25 The effect of available immigration staff ratio (av) on total passenger time (pax_t)

6.24 Description of Input Group 23

Four trials are used in the input group 23 with the same ratio of passengers per day as the previous group 22 and changing the img_t. This group focuses on the leverage of differing av% between 30 and 100 in four trials. The other four variables are fixed as F/D (number of flights per day) is fixed at 100, P/F (number of passengers per flight) is set to 240, img_t (immigration check time) is set to 2 and x_ray_t (time for customs and x-ray scanning) is set to 0.5min. A low rate of passengers per day and low immigration check time might not alter the output factors very much. See (Table 6.27).

Table 6.27 Group 23 brief detailed input output table

G23	*F/D*	*P/F*	*Img_t*	*x_ray_t*	*av*	*disp_pax*	*pax_t*	*total_pax_no*	*cap*
128	100	240	2	0.5	100	11813.5	35.09	12404.74	0.95
129	100	240	2	0.5	75	11789.5	37.2	12415.24	0.95
130	100	240	2	0.5	50	11711	37.83	12346.93	0.95
131	100	240	2	0.5	30	11793.5	36.22	12401.95	0.95

Nearly no fluctuation of the four output factors is perceived in the previous table and can be realised as pax_t equals 35-37 min (no significant difference) for approximately 24,000 daily arriving passengers distributed over 100 flights. The capacity ratio of disposed passengers to overall arrived passengers is expected to be at least 95%. The pax_t will be drawn as an almost horizontal parallel line with a rough distance of 36 min from x-axis as shown in Figure 6.26.

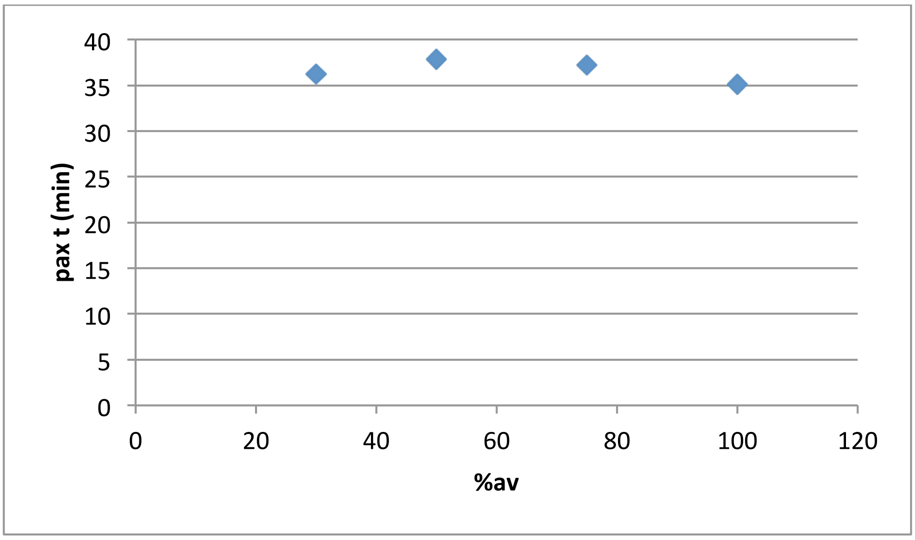


Figure 6.26 The effect of available immigration staff ratio (av) on total passenger time (pax_t)

6.25 Description of Input Group 24

This is another group that lays emphasis on av (percentage of the available immigration staff) by changing it from 30 to 100 and discovering the effect. At the same time the other factors are kept unchanged as F/D (number of flights per day) is fixed at 100, P/F (number of passengers per flight) is set to 240, img_t (immigration check time) is set to 4 min and x_ray_t (time for customs and x-ray scanning) is set to 0.5 min. The low rate of passengers per day might not show any modification on the output factors, although immigration check time is a little above normal which can lead to an effect in av ratios below 70%. The trial's details are listed in Table 6.28.

Table 6.28 Group 24 brief detailed input output table

G24	*F/D*	*P/F*	*img_t*	*x_ray_t*	*av*	*disp_pax*	*pax_t*	*total_pax_no*	*cap*
132	100	240	4	0.5	100	11766	41.48	12461.28	0.94
133	100	240	4	0.5	70	11730.5	37.16	12354.04	0.95
134	100	240	4	0.5	50	11532.5	47.16	12324.4	0.94
135	100	240	4	0.5	40	10987	107.71	12844.04	0.86
136	100	240	4	0.5	30	10144	151.13	12793.49	0.79

Practically no pronounced change is noticed on the four output factors in the first two trials, as is apparent in the above table, and can be realised as the capacity ratio of disposed passengers to overall arrived passengers is expected to be 94% (no alteration) for approximately 24,000 daily arriving passengers distributed over 100 flights. The capacity ratio starts to change when av equals 50% but a sharp fall is seen at 40% and 30%, with cap reaching 79%. On the other hand, pax_t fluctuates between 37 and 47 min in the interval between 50% to 100%, while a high delay is found at av% of 30 and 40, reaching 151 min as illustrated in Figure 6.27.

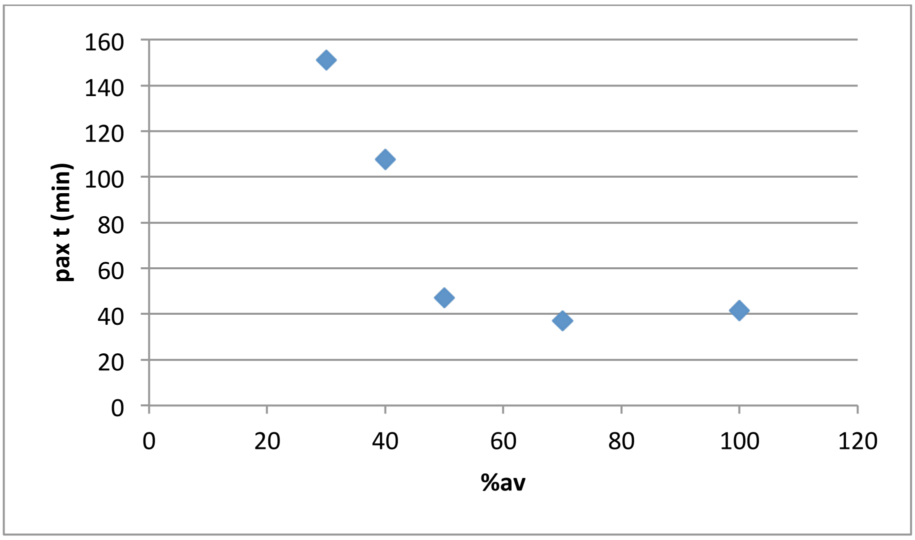


Figure 6.27 The effect of available immigration staff ratio (av) on total passenger time (pax_t)

6.26 Description of Input Group 25

The estimated number of passengers per day is assigned in this group of six trials to 25,875, in a push for more utilisation as F/D (number of flights per day) increased in this group to 115 and P/F (number of passengers per flight) decreased to 225. This is because the Arena software cannot handle a high number of WIP entities at the same time, as mentioned earlier. Immigration check time (img_t) is set to 5 and time for customs and x-ray scanning (x_ray_t) set to 0.5 min. The response might be equivalent to the last group by changing av percentage of the available immigration staff from 45% to 100% as illustrated in Table 6.29.

Table 6.29 Group 25 brief detailed input output table

G25	*F/D*	*P/F*	*img_t*	*x_ray_t*	*av*	*disp_pax*	*pax_t*	*total_pax_no*	*cap*
137	115	225	5	0.5	100	12615.5	39.64	13331.2	0.95
138	115	225	5	0.5	85	12662.5	37.89	13345.19	0.95
139	115	225	5	0.5	75	12620	43.92	13412.52	0.94
140	115	225	5	0.5	65	12443	53.72	13421.14	0.93
141	115	225	5	0.5	55	12052.5	103.68	13958.27	0.86
142	115	225	5	0.5	45	11931	98.02	13748.85	0.87

Basically no noticeable change is spotted on the four output factors on the first two trials at 100% and 85% as is obvious in Table 6.29, and can be understood as pax_time (total passenger time) equals 37 - 39 min (no significant alteration) for approximately 25,875 daily arriving passengers distributed over 115 flights with a measured capacity ratio of 95%. When av% is between 45% and 55%, total passenger time pax_t fluctuates in a high range between 98 and 103 min and the capacity ratio of disposed passengers to overall arrived passengers is estimated to be 86%. The remaining two trials when av% changes between 75% and 65% are found to form a smooth transition between the high and low outputs that can be seen in pax_time plotted in Figure 6.28.

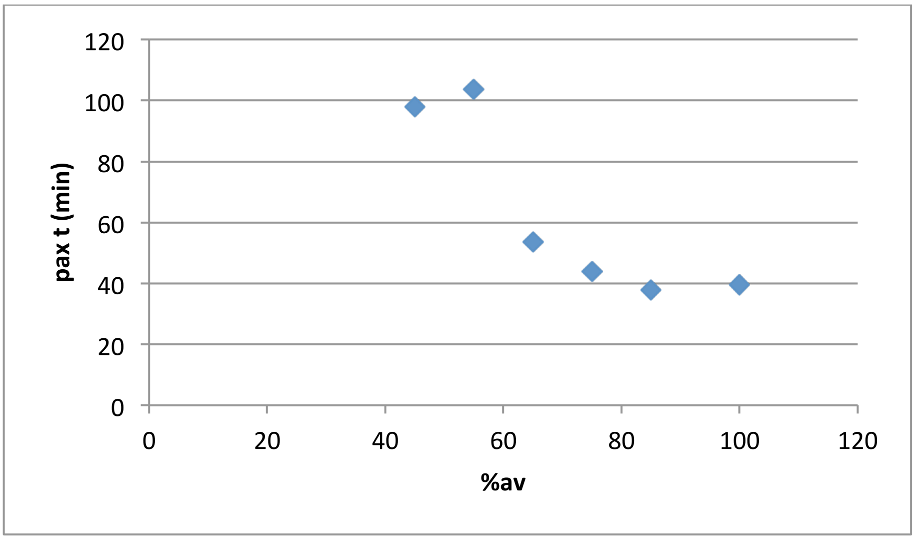


Figure 6.28 The effect of available immigration staff ratio (av) on total passenger time (pax_t)

6.27 Description of Input Group 26

The expected number of passengers per day is given in this group as 9,000 in its eight trials. This low rate allows an increase in Immigration check time (img_t) to 10 min as F/D (number of flights per day) decreased in this group to 30, and P/F (number of passengers per flight) increased to 300. Time assigned for customs and x-ray scanning (x_ray_t) is set to 1.5 min. The response might be similar to the last group by changing av percentage of the available immigration staff from 50% as illustrated in Table 6.30.

Table 6.30 Group 26 brief detailed input output table

G26	*F/D*	*P/F*	*img_t*	*x_ray_t*	*av*	*disp_pax*	*pax_t*	*total_pax_no*	*cap*
143	30	300	10	1.5	30	2702.6	322.96	4748.52	0.57
144	30	300	10	1.5	40	3597.29	197.83	4856.55	0.74
145	30	300	10	1.5	50	4086.41	123.95	4876.41	0.84
146	30	300	10	1.5	60	4105.88	121.06	4877.69	0.84
147	30	300	10	1.5	70	4182.56	119.36	4937.19	0.85
148	30	300	10	1.5	80	4142.75	122	4921.49	0.84
149	30	300	10	1.5	90	4241.5	108.51	4925.93	0.86
150	30	300	10	1.5	100	4245.33	110.72	4943.06	0.86

Essentially no visible change is marked on the four output factors in the first six trials from 100% to 50%, as it clear in the preceding Table 6.30. This can be seen as pax_time (total passenger time) equals 108 - 123 min for 30 daily arrived planes with 300 passengers on each with measured capacity ratio between 84% and 85%. When av% is 50% and 30%, total passenger time (pax_t) is 123 min and 322 min respectively. and capacity ratio of disposed passengers to overall arrived passengers reached decreases from 84% to 56% (see Figure 6.29).

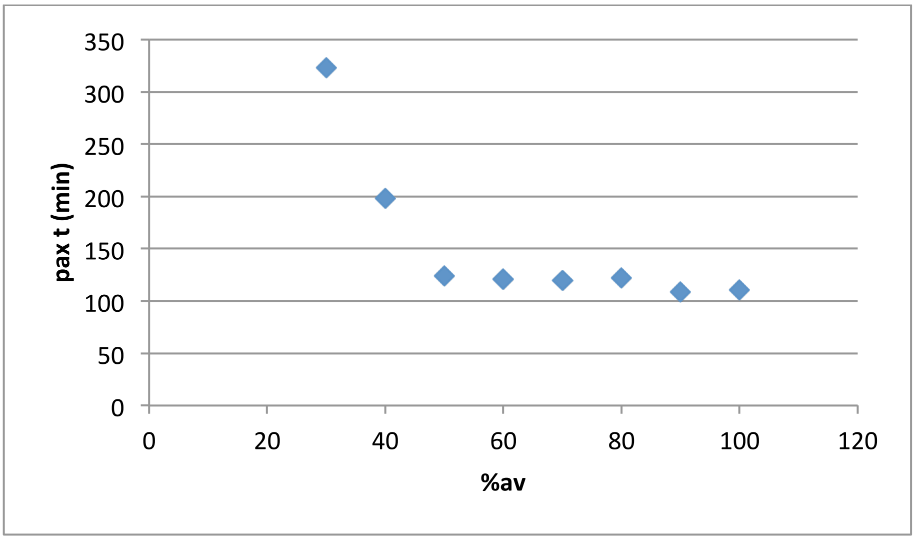


Figure 6.29 The effect of available immigration staff ratio (av) on total passenger time (pax_t)

6.28 Description of Input Group 27

Trials in this group focus on the effect of varying av% between 30 and 100 in eight trials. The other four variables remain unchanged as F/D (number of flights per day) is fixed at 30, P/F (number of passengers per flight) is set to 250, img_t (immigration check time) is set to 10 and x_ray_t (time for customs and x-ray scanning) is set to 1.5 min. The high value of img_t can have an effect on the level of utilisation and might not show a change in output factors, yet the low number of planes arriving daily might work against that. See Table 6.31.

Table 6.31 Group 27 brief detailed input output table

G27	*F/D*	*P/F*	*img_t*	*x_ray_t*	*av*	*disp_pax*	*pax_t*	*total_pax_no*	*cap*
151	30	250	10	1.5	30	2701.77	239.38	3975.05	0.68
152	30	250	10	1.5	40	3401.75	116.13	4018.34	0.85
153	30	250	10	1.5	50	3576.82	88.83	4041.77	0.88
154	30	250	10	1.5	60	3574.54	91.92	4056.25	0.88
155	30	250	10	1.5	70	3535.44	89.76	4006.8	0.88
156	30	250	10	1.5	80	3611.45	84.67	4054.39	0.89
157	30	250	10	1.5	90	3556.96	85.07	4001.79	0.89
158	30	250	10	1.5	100	3545.74	99.93	4070.92	0.87

When av varies between 50% and 100% there is nearly no change in the four output factors, as is apparent in the previous table, and can be realised as pax_t equals 85 - 99 min (no significant difference) for approximately 7,500 daily arrived passengers distributed over 250 flights. Capacity ratio of disposed passengers to overall arrived passengers is expected to be at least 87%. The pax_t will be drawn as an almost horizontal parallel line with a rough distance of 88 min from x-axis as shown in Figure 6.30. When av% is between 30% and 50% total passenger time (pax_t) fluctuates in a high range between 88 and 239 min and the capacity ratio of disposed passengers to overall arrived passengers fell to 67%.

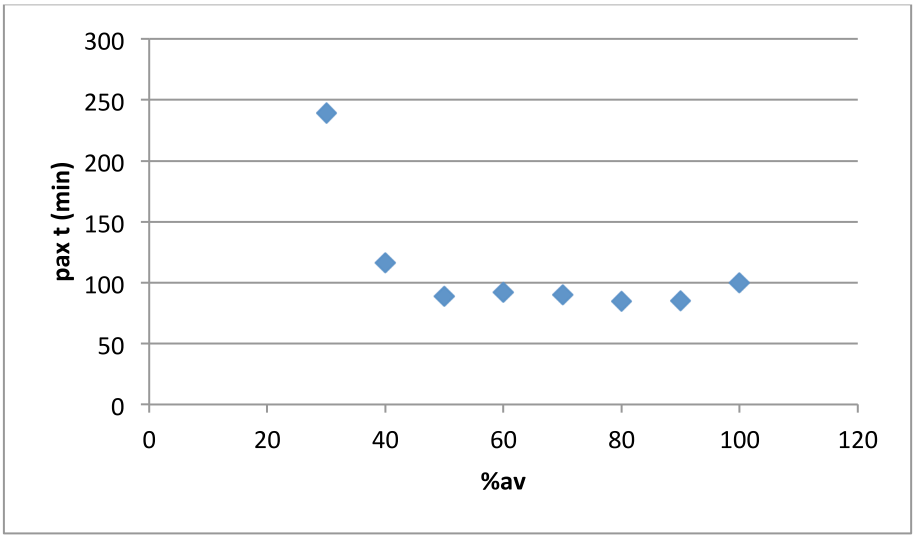


Figure 6.30 The effect of available immigration staff ratio (av) on total passenger time (pax_t)

6.29 Description of Input Group 28

Eight trials are used in the input group 28 with the ratio of 8750 passenger per day. This group highlights the influence of changing av% between 30 and 100. The other four variables are fixed as F/D (number of flights per day) is fixed at 35, P/F (number of passengers per flight) is set to 250, img_t (immigration check time) is set to 10 and x_ray_t (time for customs and x-ray scanning) is set to 1.5 min. The low rate of passengers per day and low immigration check time might not alter the output factors (see Table 6.32).

Table 6.32 Group 28 brief detailed input output table

G28	*F/D*	*P/F*	*img_t*	*x_ray_t*	*av*	*disp_pax*	*pax_t*	*total_pax_no*	*cap*
159	35	250	10	1.5	30	2703.03	309.39	4607.29	0.59
160	35	250	10	1.5	40	3552.99	178.6	4666.66	0.76
161	35	250	10	1.5	50	4061.98	111.33	4748.98	0.86
162	35	250	10	1.5	60	4158.41	95.33	4741.38	0.88
163	35	250	10	1.5	70	4158.84	100.02	4770.48	0.87
164	35	250	10	1.5	80	4097.72	110.31	4775.1	0.86
165	35	250	10	1.5	90	4127.76	101.79	4751.25	0.87
166	35	250	10	1.5	100	4099.24	103.29	4736.5	0.87

Almost no noticeable variation is found in the four output factors in the first two trials as is apparent in the above table and can be realised as the capacity ratio of disposed passengers to overall arrived passengers is expected to be 87% (no change) for approximate 8,750 daily arrived passengers distributed over 35 flights. The capacity ratio started to change when av equals 60%, with a sharp fall until 30% av, when cap equals 59%. On the other hand, pax_t fluctuates between 95 to 111min in the interval between 50% to 100% while a high delay is found on av% of 30 when it reached 309 min as demonstrated in Figure 6.31.

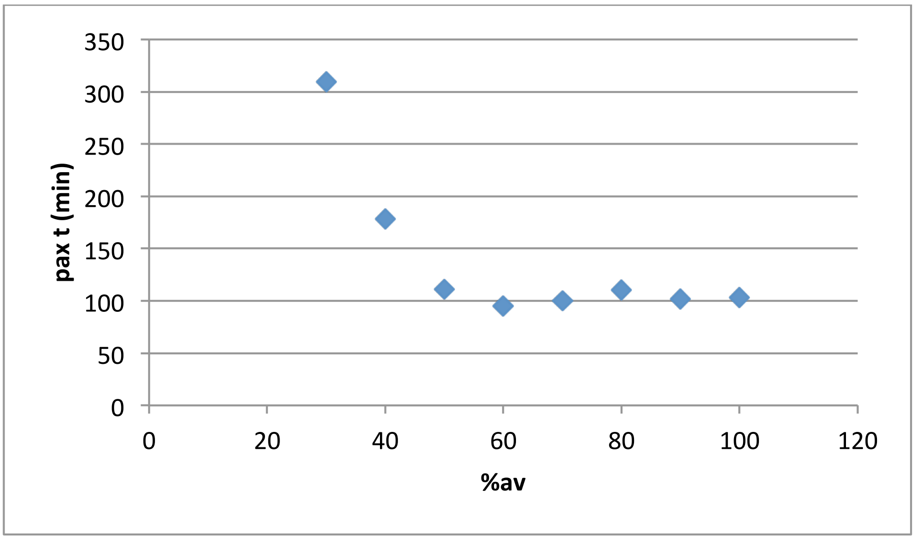


Figure 6.31 The effect of available immigration staff ratio (av) on total passenger time (pax_t)

6.30 Description of Input Group 29

This group of trials focuses on the effect of changing av% between 30 and 100 in eight trials. The other four variables remain unchanged as F/D (number of flights per day) is fixed at 35, P/F (number of passengers per flight) is set at 250, img_t (immigration check time) is set at 9 and x_ray_t (time for customs and x-ray scanning) is set to 1.5 min. The low value of img_t can lead to a low level of utilisation and might not affect the output factors. See Table 6.33.

Table 6.33 Group 29 brief detailed input output table

G29	*F/D*	*P/F*	*img_t*	*x_ray_t*	*av*	*disp_pax*	*pax_t*	*total_pax_no*	*cap*
167	35	250	9	1.5	30	3005.15	260	4608.64	0.65
168	35	250	9	1.5	40	3881.81	131.43	4696.89	0.83
169	35	250	9	1.5	50	4074.15	107.62	4736.47	0.86
170	35	250	9	1.5	60	4115.94	96.75	4713.24	0.87
171	35	250	9	1.5	70	4136.87	92.61	4705.17	0.88
172	35	250	9	1.5	80	4148.49	91.49	4709.46	0.88
173	35	250	9	1.5	90	4154.48	95.85	4738.92	0.88
174	35	250	9	1.5	100	4130.3	91.10	4688.18	0.88

Fundamentally no visible alteration is marked on the four output factors in the last five trials from 100% to 60%, as shown in the preceding Table 6.33. This can be seen as pax_time or (total passenger time) equals 91 – 96 min for 35 daily arrived planes with 300 passengers on each with measured capacity ratio between 87% and 88%. When av% is between 30% and 60% total passenger time pax_t changes to a high range between 96 and 260 min and capacity ratio of disposed passengers to overall arrived passengers decreased from 87% to 65% (see Figure 6.32).

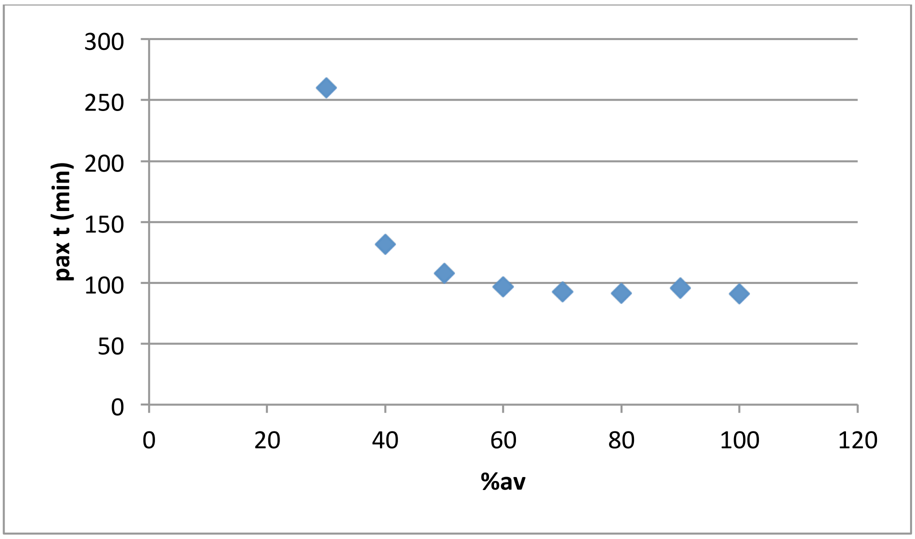


Figure 6.32 Group 29 The effect of available immigration staff ratio (av) on total passenger time (pax_t)

6.31 Description of Input Group 30

The expected number of passengers per day given in this group in its six trials is 8,750. This low rate allows an increase in immigration check time (img_t) to 10min as F/D (number of flights per day) is fixed in this group at 35 and P/F (number of passengers per flight) is fixed at 250. The time assigned for customs and x-ray scanning (x_ray_t) is set to 2 min. The reaction detected by changing av percentage of the available immigration staff from 50% and below is illustrated in Table 6.34.

Table 6.34 Group 30 brief detailed input output table

G30	*F/D*	*P/F*	*img_t*	*x_ray_t*	*av*	*disp_pax*	*pax_t*	*total_pax_no*	*cap*
175	35	250	10	2	30	2683.24	320.28	4657.65	0.58
176	35	250	10	2	50	3832.01	147.57	4761.02	0.80
177	35	250	10	2	70	3870.76	156.77	4866.18	0.80
178	35	250	10	2	90	3849.24	151.78	4800.84	0.80
179	35	250	10	2	100	3843.26	154.85	4806.45	0.80
180	35	250	10	2	40	3439.74	206.67	4745.46	0.80

While av varies between 50% - 100% there is almost no change on the four output factors as is obvious in the previous table and can be realised as pax_t equals 147 -156 min (no significant difference) for approximate 8,750 daily arriving passengers distributed over 250 flights. The capacity ratio of disposed passengers to overall arrived passengers is expected to be 80%. The pax_t will be drawn as an almost horizontal parallel line with rough distance of 150 min from x-axis as seen in Figure 6.33. When av% is between 30% and 50% total passenger time (pax_t) fluctuates in a high range between 147 and 320 min and the capacity ratio of disposed passengers to overall arrived passengers reaches 57%.

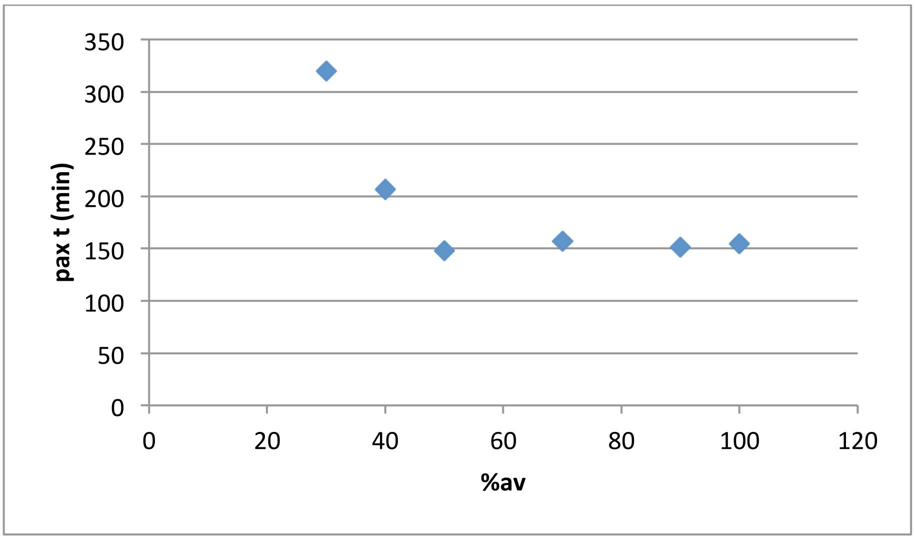


Figure 6.33 Group 30 the effect of available immigration staff ratio (av) on total passenger time (pax_t)

6.32 Description of Input Group 31

This group of trials focuses on the effect of changing av% between 30 and 100 in four trials. The other four variables remain unchanged as F/D (number of flights per day) is fixed at 30, P/F (number of passengers per flight) is set to 300, img_t (immigration check time) is set to 10 and x_ray_t (time for customs and x-ray scanning) is set to 2 min. The low value of img_t can lead to a low level of utilisation and might not show an effect on the output factors (see Table 6.35).

Table 6.35 Group 31 brief detailed input output table

G31	F/D	P/F	img_t	x_ray_t	av	disp_pax	pax_t	total_pax_no	cap
181	30	300	10	2	30	2676.63	351.75	4902.98	0.55
182	30	300	10	2	50	3739.38	189.11	5024.79	0.74
183	30	300	10	2	70	3877.48	171.12	4989.95	0.78
184	30	300	10	2	100	3851.83	180.32	5032.18	0.77

Basically no noticeable change is found on the four output factors in the trials between 100% and 50% as it clear in the previous Table 6.35, and can be understood as pax_time or (total passenger time) equals 171 - 189 min (no significant difference) for approximate 9,000 daily arriving passengers distributed over 30 flights with measured capacity ratio between 74% and 77%. When av% is between 30% and 50% total passenger time pax_t fluctuate in high range between 189 and 351 min and capacity ratio of disposed passengers to overall arrived passengers is estimated to reach 54% (see Figure 6.34).

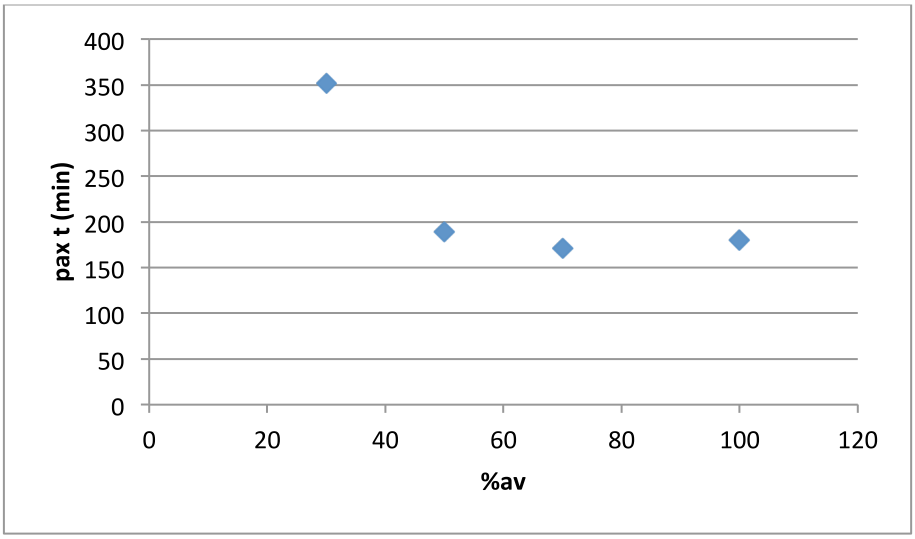


Figure 6.34 Group 31 the effect of available immigration staff ratio (av) on total passenger time (pax_t)

6.33 Description of Input Group 32

Four trials are used in the input group 32 with the ratio of 18,000 passengers per day. This group focuses on the effect of changing av% between 30 and 100. The other four variables are fixed as F/D (number of flights per day) is fixed at 60, P/F (number of passengers per flight) is set to 300, img_t (immigration check time) is set to 1 min and x_ray_t (time for customs and x-ray scanning) is set to 1min (see Table 6.36).

Table 6.36 Group 32 brief detailed input output table

G32	*F/D*	*P/F*	*img_t*	*x_ray_t*	*av*	*disp_pax*	*pax_t*	*total_pax_no*	*cap*
185	60	300	1	1	30	8116.5	120.4	9658.18	0.84
186	60	300	1	1	50	8138.73	112.64	9599.31	0.85
187	60	300	1	1	70	8234.25	104.38	9599.24	0.86
189	60	300	1	1	100	8218.39	103.93	9560.99	0.86

When av varies between 70% and 100% no significant alteration is made on the four output factors as is apparent in the previous table, and can be realised as pax_t equals 104 min. The capacity ratio of disposed passengers to overall arriving passengers is estimated to be equal to 86%. The pax_t will be drawn as an almost horizontal parallel line with distance of 104 min from the x-axis as seen in Figure 6.35. When av% is between 30% and 70% total passenger time pax_t fluctuates in a high range between 104 and 120 min (see Figure 6.35) and the capacity ratio of disposed passengers to overall arrived passengers reaches 84%.

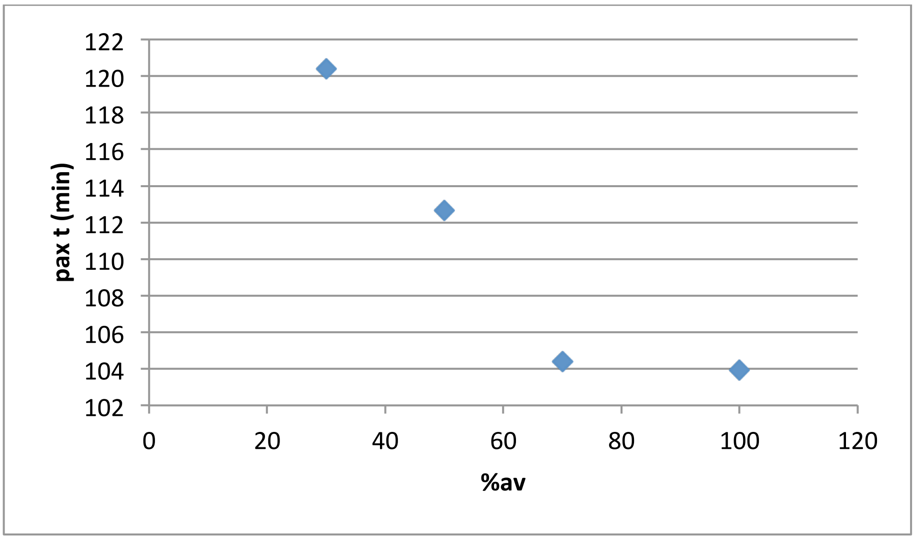


Figure 6.35 Group 32 the effect of available immigration staff ratio (av) on total passenger time (pax_t)

6.34 Description of Input Group 33

This group belongs to the same set of groups that study the effect of av%, yet it is considered to be different in a way as high utilisation is found in no passengers with low x_ray_t. In this group av% varies between 60 and 100. The other four variables are fixed as F/D (number of flights per day) is fixed at 60, P/F (number of passengers per flight) is set to 300, img_t (immigration check time) is set to 1 min and x_ray_t (time for customs and x-ray scanning) is set to1 min (see Table 6.37).

Table 6.37 Group 33 brief detailed input output table

G33	F/D	P/F	img_t	x_ray_t	av	disp_pax	pax_t	total_pax_no	cap
192	95	300	4	0.5	60	13175.58	82.84	14836.88	0.89
193	95	300	4	0.5	65	13587.13	61.45	14816.54	0.92
194	95	300	4	0.5	80	13686.17	52.58	14739.3	0.93
195	95	300	4	0.5	90	13822.68	47.74	14773.96	0.94
196	95	300	4	0.5	100	13867.35	45.03	14765.42	0.94

This group can be divided to two categories: pax_t is decreasing as av increases yet a sharp decrease is located between 60% and 65% with pax_t fluctuating from 61 to 83 min then a smoother decrease is observed between 65% and 100% with pax_t variation from 61 to 45 min respectively. The capacity ratio of disposed passengers to overall arrived passengers observed an increase from 88% to 92% when av% increased from 60% to 65% and continues to increase until it reaches 94% when av% equals 100% as illustrated in Figure 6.36.

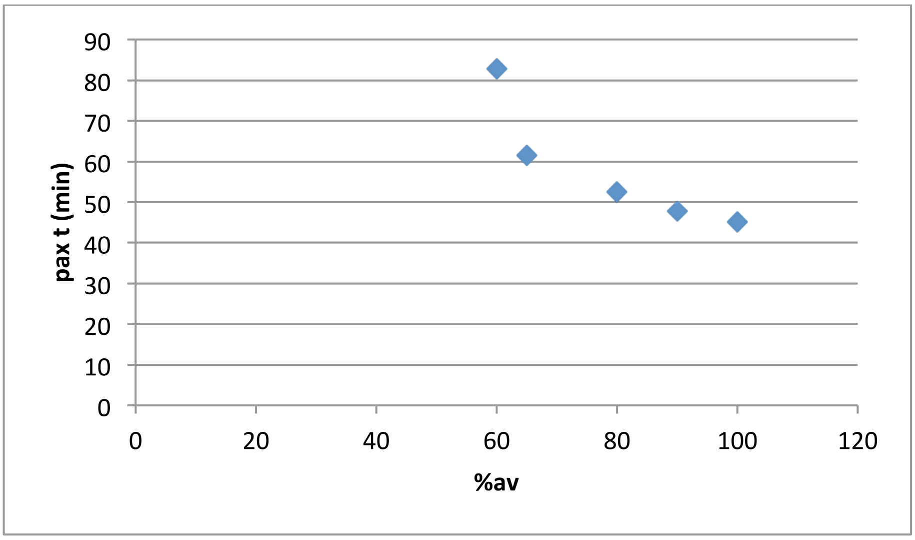


Figure 6.36 Group 32 the effect of available immigration staff ratio (av) on total passenger time (pax_t)

6.35 Description of Input Group 34

The total ratio of 20,700 passengers per day created in this group is divided between 90 arriving planes. In this group av varies from 55% to 100%. The other four variables are fixed as F/D (number of flights per day) is fixed at 90, P/F (number of passengers per flight) is set to 230, img_t (immigration check time) is set to 5 min and x_ray_t (time for customs and x-ray scanning) is set to 0.5 min as listed in Table 6.38.

Table 6.38 Group 34 brief detailed input output table

G34	*F/D*	*P/F*	*imgt*	*x-rayt*	*av*	*disp_pax*	*pax_t*	*total_pax_no*	*cap*
197	90	230	5	0.5	55	8287.24	163.35	10675.62	0.78
198	90	230	5	0.5	60	8980.16	118.27	10714.87	0.84
199	90	230	5	0.5	65	9429.52	89.74	10747.1	0.88
200	90	230	5	0.5	70	9882.65	60.07	10759.03	0.92
201	90	230	5	0.5	80	10095.01	41.54	10695.17	0.94
202	90	230	5	0.5	90	10139.91	39.04	10702.89	0.95
203	90	230	5	0.5	100	10102.43	38.06	10651.86	0.95

A high output fluctuation is found in this group especially in the time aspect. A sharp decrease (from 163 min to 41min) is observed as av% increases from 55% to 80% then a smother decrease (from 41min to 38 min) is perceived between 80% and 100%. The capacity ratio of disposed passengers to overall arrived passengers observed is increasing from 77% to 94% while av is increasing from 55% to 80%, and then stays steady until av reaches 100 (see Figure 6.37).

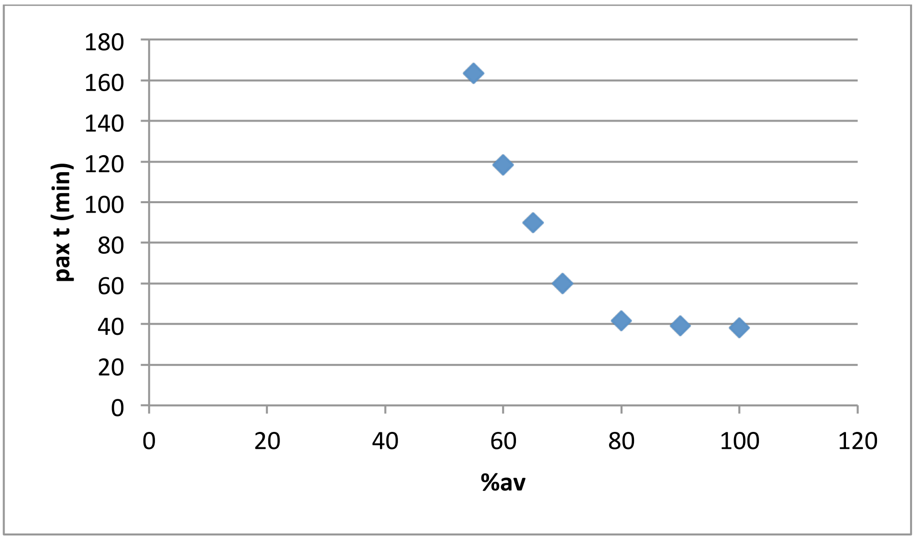


Figure 6.37 Group 34 the effect of available immigration staff ratio (av) on total passenger time (pax_t)

6.36 Description of Input Group 35

This group of trials focuses on the influence of changing av% between 55 and 100 in six trials. The other four variables remain unchanged as F/D (number of flights per day) is fixed at 90, P/F (number of passengers per flight) is set to 200, img_t (immigration check time) is set to 7 and x_ray_t (time for customs and x-ray scanning) is set to 0.5 min. The high value of img_t can lead to a high level of utilisation and might not show fluctuation of output factors (see Table 6.39).

Table 6.39 Group 35 brief detailed input output table

G35	*F/D*	*P/F*	*img_t*	*x_ray_t*	*av*	*disp_pax*	*pax_t*	*total_pax_no*	*cap*
204	90	200	7	0.5	55	7091.2	172.98	9295.61	0.76
205	90	200	7	0.5	60	7695.87	127.79	9327.5	0.83
206	90	200	7	0.5	70	8524.82	65.84	9362.71	0.91
207	90	200	7	0.5	80	8771.15	44.02	9323.97	0.94
208	90	200	7	0.5	90	8819.75	38.60	9303.42	0.95
209	90	200	7	0.5	100	8838.8	36.26	9292.48	0.95

Passengers' total time spent in the terminal (Pax_t) fluctuates between 36 and 172 min and capacity ratio of disposed passengers to overall arrived passengers changes from 76% to 95%. However, pax_t fluctuates a great deal between 36 and 172 min (see Figure 6.38).

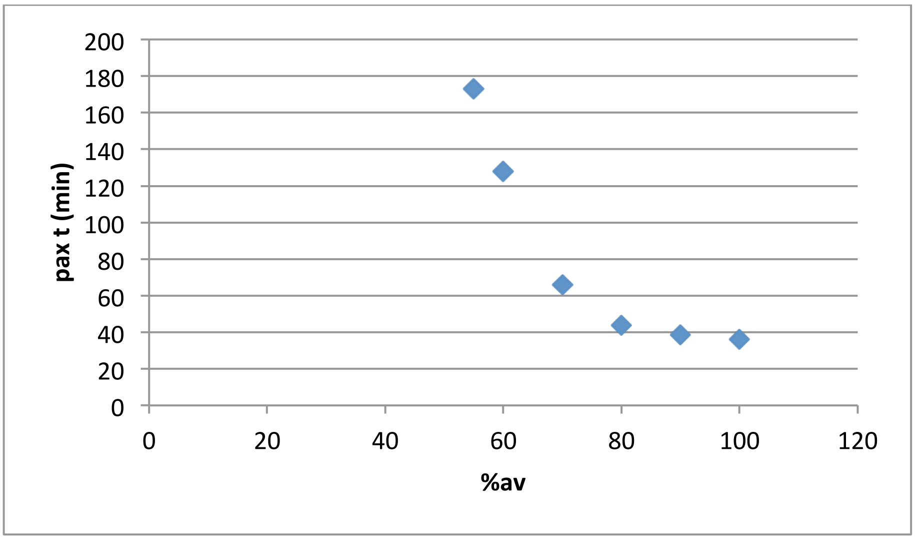


Figure 6.38 Group 35 the effect of available immigration staff ratio (av) on total passenger time (pax_t)

6.37 Description of Input Group 36

Nine trials are used in the input group 36 with the ratio of 13,500 passengers per day. This group focuses on the effect of varying av% between 25% and 100%. The other four variables are fixed as F/D (number of flights per day) is fixed at 45, P/F (number of passengers per flight) is set to 300, img_t (immigration check time) is set to 5 min and x_ray_t (time for customs and x-ray scanning) is set to 1 min as shown in Table 6.40.

Table 6.40 Group 36 brief detailed input output table

G36	*F/D*	*P/F*	*img_t*	*x_ray_t*	*av*	*disp_pax*	*pax_t*	*total_pax_no*	*cap*
210	45	300	5	1	25	4571.49	262.64	7057.53	0.65
211	45	300	5	1	27	4841.13	236.87	7085.14	0.68
212	45	300	5	1	30	5356	192.5	7180	0.75
213	45	300	5	1	35	6169.52	105.35	7172.26	0.86
214	45	300	5	1	50	6498.34	82.48	7275.21	0.89
215	45	300	5	1	60	6460.8	76.74	7181.89	0.90
216	45	300	5	1	80	6408.82	81.91	7183.82	0.89
217	45	300	5	1	90	6484.06	77.36	7211.54	0.90
218	45	300	5	1	100	6390.25	80.66	7151.19	0.89

This group can be segmented into two groups: pax_t is sharply decreasing while av increases between 25% and 50% with pax_t fluctuation from 262 to 82 min then a steady movement with no great fluctuation is experienced between 50% and 100% with pax_t variation from 77 to 82 min as illustrated in Figure 6.39. The capacity ratio of disposed passengers to overall arrived passengers observes an increase from 64% to 89% when av% increased from 25% to 50% and it stays at 90% when av% varies between 50% and 100%.

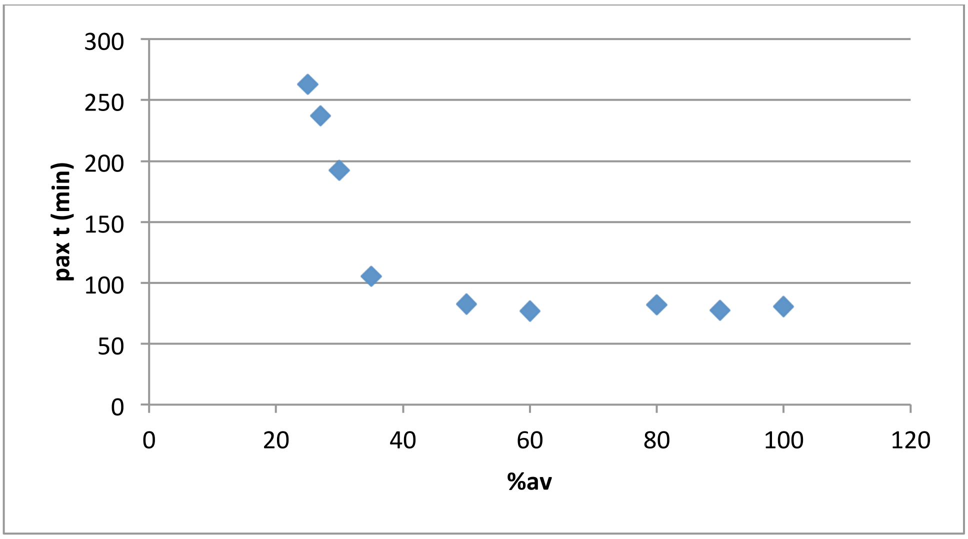


Figure 6.39 Group 36 the effect of available immigration staff ratio (av) on total passenger time (pax_t)

6.38 Description of Input Group 37

The estimated number of passengers per day assigned to this group is 28,500 in its seven trials, driving towards greater utilisation as F/D (number of flights per day) increases to 95 and P/F (number of passengers per flight) stays at 300. Immigration check time (img_t) is set to 4 and time for customs and x-ray scanning (x_ray_t) is set to 0.5 min. The response might be equivalent to the last group by changing av percentage of the available immigration staff from 60% to 100% as illustrated in Table 6.41.

Table 6.41 Group 37 brief detailed input output table

G37	*F/D*	*P/F*	*imgt*	*x-rayt*	*av*	*disp_pax*	*pax_t*	*total_pax_no*	*cap*
219	95	300	4	0.5	60	13175.58	82.84	14836.88	0.89
220	95	300	4	0.5	65	13587.13	61.45	14816.54	0.92
221	95	300	4	0.5	70	13748.75	50.33	14752.61	0.93
222	95	300	4	0.5	75	13725.81	47.86	14683.94	0.93
223	95	300	4	0.5	85	13772.81	47.351	14718.5	0.94
224	95	300	4	0.5	90	13822.68	47.74	14773.96	0.94
225	95	300	4	0.5	100	13867.35	45.03	14765.42	0.94

The capacity ratio of disposed passengers to overall arrived passengers is observed as increasing from 88% to 93% when av% increases from 60% to 70%, and it stays at 94% when av% varies between 70 and 100%. Pax_t decreases rapidly from 82 min to 47 min in av% range between 60% and 75% then a steady behaviour is found between 75% and 100% as it reaches 45 min as seen in Figure 6.40.

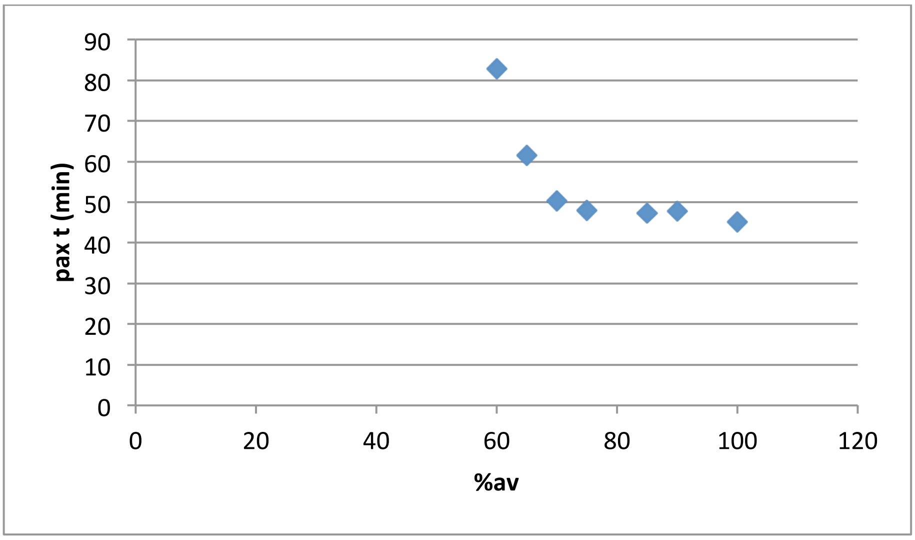


Figure 6.40 Group 37 the effect of available immigration staff ratio (av) on total passenger time (pax_t)

6.39 Description of Input Group 38

This group of trials focuses on the effect of varying av% between 20 and 100 in six trials. The other four variables remain unchanged as F/D (number of flights per day) is fixed at 30, P/F (number of passengers per flight) is set to 300, img_t (immigration check time) is set to 7 and x_ray_t (time for customs and x-ray scanning) is set to 1 min. The high value of img_t can lead to a high level of utilisation and might not show fluctuation on output factors, yet a low F/D might bring up stability in the outputs (see Table 6.42).

Table 6.42 Group 38 brief detailed input output table

G38	*F/D*	*P/F*	*img_t*	*x_ray_t*	*av*	*disp_pax*	*pax_t*	*total_pax_no*	*cap*
227	30	300	7	1	20	2649.93	326.57	4717.99	0.56
228	30	300	7	1	30	3809.55	149.33	4758.19	0.80
229	30	300	7	1	40	4369.43	72.56	4819.7	0.90
230	30	300	7	1	50	4360.92	68.70	4784.79	0.91
231	30	300	7	1	60	4360.84	66.02	4767.47	0.91
232	30	300	7	1	70	4331.22	72.59	4781.61	0.90
233	30	300	7	1	80	4367.49	68.93	4791.73	0.91
234	30	300	7	1	90	4370.92	68.27	4791.49	0.91
235	30	300	7	1	100	4331.09	66.26	4739.83	0.91

The capacity ratio of disposed passengers to overall arrived passengers observed an increase from 56% to 91% when av% increased from 20% to 50% and it remains at 90% to 91% when av% changes from 50% to 100%. Pax_t drops sharply from 326 min to 68 min in av% range between 20% and 50% then stable behaviour is found between 50% and 100% as it reaches 66 min as shown in Figure 6.41.

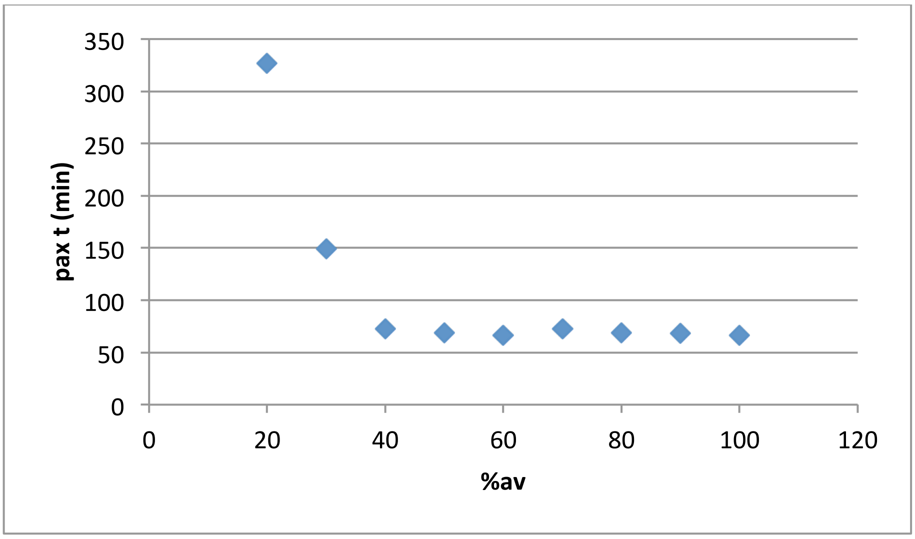


Figure 6.41 Group 38 the effect of available immigration staff ratio (av) on total passenger time (pax_t)

6.40 Description of Input Group 39

This is another group that highlights av (percentage of the available immigration staff) by fluctuating it from 13 to 100 and discovering the effect. Other factors are left constant - F/D (number of flights per day) is fixed at 30, P/F (number of passengers per flight) is set to 300, img_t (immigration check time) is set to 5 min and x_ray_t (time for customs and x-ray scanning) is set to1.5 min. The low rate of passengers per day might not show modification on the output factors, alhough immigration check time is a little above normal which can lead to an effect in ratios below 40%. The trial's details are listed in Table 6.43.

Table 6.43 Group 39 brief detailed input output table

G39	*F/D*	*P/F*	*img_t*	*x_ray_t*	*av*	*disp_pax*	*pax_t*	*total_pax_no*	*cap*
236	30	300	5	1.5	13	2556.22	348.2	4755.02	0.54
237	30	300	5	1.5	15	2899.71	292.54	4755.02	0.61
238	30	300	5	1.5	16	3061.45	274.14	4792.54	0.64
239	30	300	5	1.5	18	3212.63	245.37	4765.99	0.67
240	30	300	5	1.5	19	3366.94	226.89	4804.36	0.70
241	30	300	5	1.5	20	3509	201.27	4785.34	0.73
242	30	300	5	1.5	22	3767.59	172.82	4867.26	0.77
243	30	300	5	1.5	60	4153.89	123.24	4933.71	0.84
244	30	300	5	1.5	80	4178.72	113	4895.73	0.85
245	30	300	5	1.5	100	4186.04	106.64	4857.79	0.86

This group can be segmented into two groups: pax_t is sharp decreasing while av increases between 13% and 22% with pax_t fluctuating from 348 min to 172 min then a steady decrease is experienced between 60% and 100% with pax_t variation from 123 to 106 min as demonstrated in Figure 6.42. The capacity ratio of disposed passengers to overall arrived passengers observes an increase from 53% to 84% when av% increases from 13% to 60% and it increases to 86% when av% equals 100%.

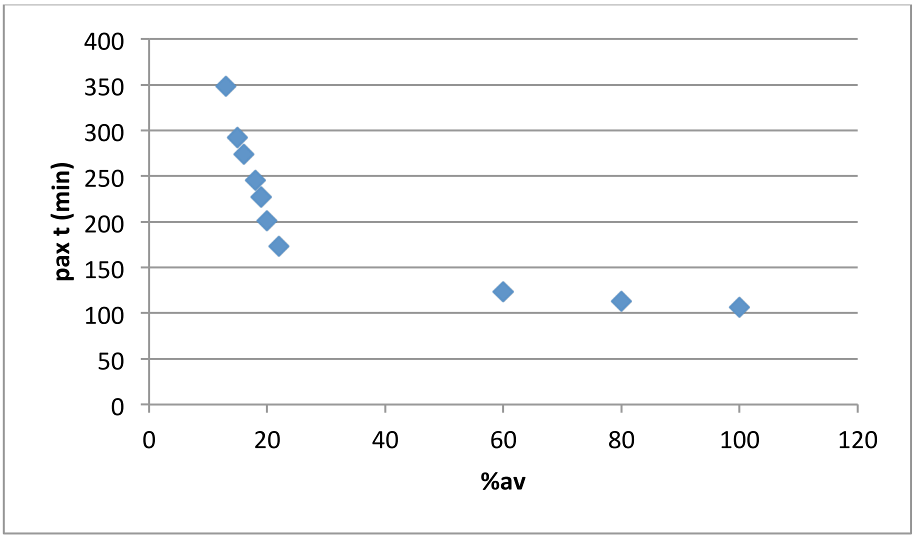


Figure 6.42 Group 39 the effect of available immigration staff ratio (av) on total passenger time (pax_t)

6.61 Description of Input Group 40

Eight trials are used in the input group 40 with the ratio of 7,500 passengers per day. This group highlights the effect of varying av% between 15% and 100%. The other four variables are fixed as F/D (number of flights per day) is fixed at 30, P/F (number of passengers per flight) is set to 250, img_t (immigration check time) is set to 5 min and x_ray_t (time for customs and x-ray scanning) is set to 1.5 min as shown in Table 6.44.

Table 6.44 Group 40 brief detailed input output table

G40	*F/D*	*P/F*	*imgt*	*x-rayt*	*av*	*disp_pax*	*pax_t*	*total_pax_no*	*cap*
246	30	250	5	1.5	15	2858.55	213.19	3983.06	0.72
247	30	250	5	1.5	17	3060.35	176.98	3995.61	0.77
248	30	250	5	1.5	20	3311.6	133.07	4012.87	0.83
249	30	250	5	1.5	22	3504.84	101.13	4036.36	0.87
250	30	250	5	1.5	25	3569.77	87.3323	4027.31	0.89
251	30	250	5	1.5	30	3569.44	90.8452	4044.95	0.88

252	30	250	5	1.5	60	3529.33	98.6237	4054.44	0.87
253	30	250	5	1.5	100	3594.39	83.5435	4032.22	0.89

Disposed passengers are observed to be increasing from 2,858 to 3,594 while av increases from 15% to 100%. There is stability (at value 3,569) measured between the ranges 25% and 30%, and a small drop (with value 3,529) when av% equals 60. The capacity fluctuates accordingly from 71% and 89%, the major fluctuation found when av% varies between 15% and 22%. Pax_t is found to be behaving in the opposite direction: the value is decreasing from 213 min to 83 min, with this occurring most sharply when av% increases from 15% to 25% as shown in Figure 6.43.

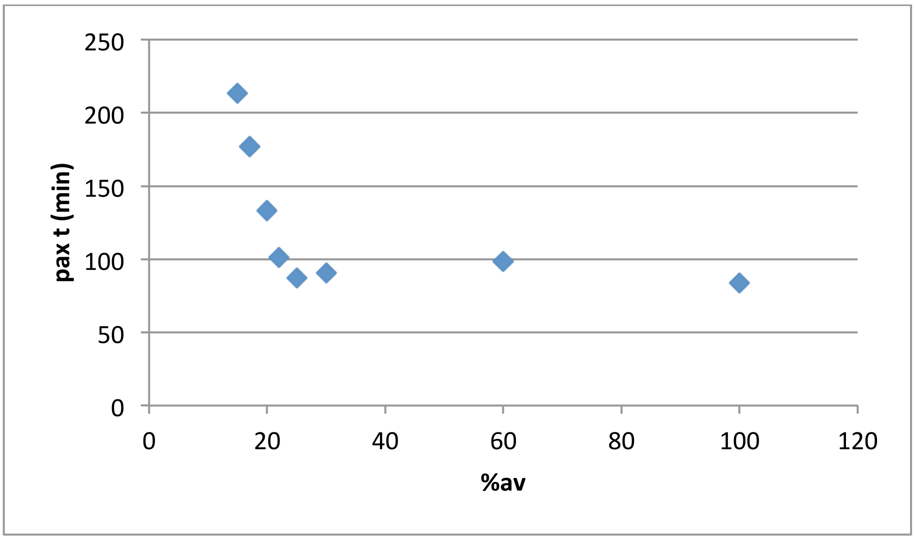


Figure 6.43 Group 40 the effect of available immigration staff ratio (av) on total passenger time (pax_t)

6.62 Summary

This chapter has exposed results gathered from executing the simulation model with initially pax_t time as a sample of influence on output. Groups of diverse conditions and scenarios are considered in Arena to get outputs that can be analysed in the next chapter for preparing a mathematical modelling of the system behaviour by varying the inputs of the simulation model that can allow an optimisation study on the system as has been set as an aim of this research. The values intended to be varied for one predictor along with fixing the others in way to be reasonable within the capacity of the airport and the software as that mentioned in the being of the chapter. Some trials are made after examining the surface viewer in MATLAB as it can be seen in chapter seven. Validation is made with some gathered data from the spread sheet as it can be seen in appendix B.

Chapter 7 Optimisation and Results Analysis

7.1 Introduction to analysis

The aim of this thesis is to develop an optimisation system to improve the performance of airport terminal operations. One of the objectives of this research is to create a model that can predict the airport capacity in order for its operational efficiency to be optimised. The extracted output from the Arena software which was described in chapter six is analysed in this chapter, which investigates the relation between variables using regression and fuzzy logic to generate an appropriate model. The model after verification is used to optimise the airport operation using both GA and PSO. Correlation analysis will show whether or not the variables can be associated to each other, revealing the significant level that can determine the occurrence of that correlation beyond the sample of trials. Then linear regression is carried out with several steps, starting with identification of the independent variables. The overall model fitness accuracy summary is produced to observe the model's ability to predict the airport behaviour. Then, an ANOVA table is used to examine whether the regression model is appropriate for the data. A Levenberg-Marquardt regression algorithm is also considered to improve the regression model's accuracy. Furthermore, adaptive neuro fuzzy system is utilized to develop a more accurate model. The developed model is then used in conjunction with PSO and GA in order to find the best operating conditions of the airport, manipulating the input variables in order to maximise operational efficiency.

7.2 Linear correlation

Correlations between variables can be identified clearly as described in the sixth chapter, using statistics from Chapter 6's results as the sample, which can be identified as N equals 248.

F/D shows a significant correlation to all variables (Pearson's correlation test, $p \leq 0.01$), except av%, while total_pax_no is found to have the strongest correlation with a high positive correlation coefficient ($r=0.746$, $p<0.01$). Then disp_pax is the second highest correlated variable ($r=0.731$, $p<0.01$). Little correlation of F/D can be seen at the same level with P/F, img_t and av% which means that there is not enough evidence to say this correlation exists beyond this sample. Other tests show moderate to low associations with F/D, although the tests are still statistically significant (p<0.05).

On the other hand, the second variable P/F has no high observed correlation with any of the other variables yet there is significant correlation (p<0.01) with each of img_t, x-ray_t, av% and cap. A positive correlation is found in img_t, disp_pax, pax_t and total_pax_no., while the rest are negative. There is no indication that correlation occurs outside this sample for disp_pax, pax_t and total_pax_no.

The third variable img_t is observed to have positive correlation only with pax_t and P/F, all the correlations are found to be significant except for x-ray_t and pax_t, yet all correlations are low.

The fourth variable x_ray_t is found to have positive correlation only with av% and pax_t. High correlation is only observed with pax_t with a significant level (p<0.01), img_t and cap are found to have moderate strength of correlation, yet only cap can be identified as statistically significant at the same level. A low strength correlation is seen with disp_pax and total_pax_no although the test is still statistically significant (p<0.01); the rest have very little, if any, strength in their correlation.

The fifth variable av% is correlated positively with F/D, x-ray_t, disp_pax, total_pax_no and cap while the rest have negative correlation. Only P/F, img_t, pax_t and cap correlations are identified as statistically significant. No high or moderate correlation strength is observed, however low strength correlation is found with P/F and cap.

The sixth variable disp_pax is observed to have positive correlation with the following: F/D, P/F, av, total_pax_no, and cap where statistical significant correlation is found with F/D, img_t, x-ray_t, pax_t, total_pax_no, and cap. A very high strength correlation is found with total_pax_no, and below that a high correlation is observed with F/D. There is low correlation between disp_pax and img_t, x-ray_t, pax_t and cap.

The seventh variable pax_t is observed to have positive correlation with P/F, img_t and x-ray_t, while statistically significant correlations are seen with F/D, x-ray_t, av%, disp_pax, total_pax_no and cap. A high strength correlation is observed with cap and x-ray_t whereas there are low strength correlations with F/D, d and total_pax_no.

The eighth variable total_pax_no is observed to have a positive correlation with F/D, P/F, av%, disp_pax and cap, while statistically significant correlations are observed between the variable and the following: F/D, img_t, x-ray_t, disp_pax, pax_t and cap. A very high strength correlation is found with disp_pax and a high strength correlation is associated with F/D. Moderate correlation with both P/F and av% is found and a low strength correlation observed with all of the following: img_t, x-ray_t, pax_t, and cap.

The ninth variable cap has a high correlation observed with Pax_t, moderate correlation with x-ray_t and low with the rest of the variables. A significant correlation ($p<0.01$) is observed with all variables. Positive correlation is found in F/D, av%, disp_pax, and total_pax_no while the rest are negative (see Table 7.1).

Table 7.1 Correlations between all variables using Pearson correlation

		P/F	*img_t*	*x-ray_t*	*av%*	*Disp*	*Pax_t*	*Total*	*Cap*
F/D	Pearson Correlation	-0.178**	-0.263**	-0.453**	0.101	.731**	-0.366**	0.746**	0.301**
	Sig. (2-tailed)	0.005	0	0	0.112	0	0	0	0
	N	248	248	248	248	248	248	248	248
P/F	Pearson Correlation		0.288**	-0.174**	-0.353**	0.014	0.117	0.065	-0.298**
	Sig. (2-tailed)		0	0.006	0	0.828	0.067	0.311	0
	N		248	248	248	248	248	248	248
img_t	Pearson Correlation			-0.05	-0.216**	-0.355**	0.117	-0.333**	-0.229**
	Sig. (2-tailed)			0.437	0.001	0	0.065	0	0
	N			248	248	248	248	248	248
x-ray_t	Pearson Correlation			1	0.103	-0.484**	0.726**	-0.470**	-0.617**
	Sig. (2-tailed)				0.104	0	0	0	0
	N				248	248	248	248	248
av	Pearson Correlation					0.117	-0.270**	0.059	0.398**
	Sig. (2-tailed)					0.066	0	0.354	0
	N					248	248	248	248
Disp_pax	Pearson Correlation						-0.407**	0.992**	0.445**
	Sig. (2-tailed)						0	0	0
	N						248	248	248
Pax_t	Pearson Correlation							-0.326**	-0.886**
	Sig. (2-tailed)							0	0
	N							248	248
Total_pax_no	Pearson Correlation								0.350**
	Sig. (2-tailed)								0
	N								248

**. Correlation is significant at the 0.01 level (2-tailed).

7.3 Regression Model

Linear regression is a method to predict the value of a variable (the dependent variable) based on the value of another variable (the independent variable) by representing the relationship between a scalar dependent variable 'Y' and one or more explanatory variables indicated as 'X' (statistics.laerd.com, n.d.). When there is only one descriptive variable used, the regression model is called a "simple linear regression". Simple linear regression consists of two functions: the mean function and the variance function (Weisberg, 2005). This tool is only appropriate if the relationship between both variables is linear. A linear relationship can be checked after obtaining the values and using some inputs to produce a simulation model to compare with the linear regression.

After correlation, linear regression is considered the next level in the analysis journey. Generating a prediction based on the knowledge of other variables is the main purpose of this analysis. The dependent variable, or outcome variable, is the variable being predicted - in this case pax_t. The independent variable, or predictor variable, is a variable used as an input in the prediction. The linear regression is displayed via SPSS software, which aids in the understanding of the outcomes from that regression.

7.3.1 Passenger time Regression

Firstly the variables shown in Table 7.2 are a list of all the predictors which are used in the regression equation, the variables are av%, F/D, img_t and x-ray_t and the dependent variable is pax_t.

Table 7.2 Variables Entered/Removed[a] for Dependent Variable: Pax_t

Model	Variables Entered	Variables Removed	Method
1	av, F/D, img_t, P/F, x-ray_t[b]	.	Enter

a. Dependent Variable: Pax_t
b. All requested variables entered.

Secondly, the overall model fitness accuracy is described in Table 7.3. The first column is for R which decides the ability to predict the output using the predictor with a reported value of 0.821. The second column is the square of R with a value of 0.673 to provide a more accurate reading of that measure by indicating the variance of the predictor. Finally, an estimation of the standard error with a value of 53.198 indicates the amount that R differs from the sample and the following sample.

Table 7.3 Pax_t regression model summary

Model	R	R Squared	Adjusted R Squared	Std. Error of the Estimate
1	0.821[a]	0.673	0.667	53.198

a. Predictors: (Constant), av, F/D, img_t, P/F, x-ray_t

The "**R**" column shows *R,* the multiple correlation coefficients. *R* can be treated as one measure of the quality of the estimation of the capacity variable as an dependent variable. A value of 0.821 pointed out a good level of prediction. The "**R Squared**" column shows the R^2 value (also named the determination coefficient), which is the ratio of variance in the predicted variable that can be clarified by the predictors (in theory, it is the ratio of variation calculated by the capacity regression model and beyond the mean model). It can be observed from the value of 0.673 that the predictors describe 67.3% as the variability of the capacity variable as a dependent variable. Nonetheless, it is necessary to calculate and understand "**Adjusted R Square**" (*adj.* R^2) to accurately report on the given data (statistics.laerd.com n.d.).

The following analysis of variance found in Table 7.4 Pax_t regression ANOVA[a] test - for more information see the ANOVA test description (Miller, 1997). The F-test outcome shown in Table 7.4 suggests that the regression model fits the data as the last column presents less than 0.001. The relationship between these variables (dependent and independent) is illustrated as a straight line.

Table 7.4 Pax_t regression ANOVA[a] test

Model		Sum of Squares	df	Mean Square	F	Sig.
1	Regression	1412612.529	5	282522.506	99.830	.000[b]
	Residual	684869.213	242	2830.038		
	Total	2097481.742	247			

a. Dependent Variable: Pax_t
b. Predictors: (Constant), av, F/D, img_t, P/F, x-ray_t

The independent variable coefficient b, beta and the significance of each predictor are presented in the Table 7.5. The first column 'Model' lists the independent variables or predictors. The second column 'Unstandardized Coefficients' contains a constant value or the value of X by assuming Y=0 as well as **b** the dependent variable coefficient. The third column named 'Standardized Coefficients' lists all the beta coefficients. Beta in regression results should have the same value as the correlation coefficient, unless it is a multiple regression like this case. The last column in the table lists the significance of the association among the predictors and the predicted variable, to explain how probable it is that to discover a correlation this strong in the existing sample (strath.ac.uk, n.d ; ats.ucla.edu, n.d.). Here the regression equation can be illustrated as:

$$\begin{aligned} \text{Pax\_t} = {} & 48.994 + 0.204\times \text{F/D} + 0.227\times \text{P/F} + 2.184\times \text{img\_t} \\ & + 37.415\times \text{xray\_t} - 0.974\times \text{av} \end{aligned} \tag{7.1}$$

Table 7.5 Pax_t regression Coefficients[a]

Model		Unstandardized Coefficients		Standardized Coefficients	t	Sig.
		B	Std. Error	Beta		
1	(Constant)	48.994	24.012		2.040	0.042
	F/D	0.204	0.111	0.082	1.844	0.066
	P/F	0.227	0.063	0.149	3.583	0.000
	img_t	2.184	1.198	0.073	1.822	0.070
	x-ray_t	37.415	1.977	0.823	18.923	0.000
	av	-0.974	0.131	-0.296	-7.451	0.000

a. Dependent Variable: Pax_t

7.3.2 Capacity regression

The same can be said for the capacity variables as shown in Table 7.6. The regression variables are av%, F/D, img_t and x-ray_t and the dependent variable is cap.

Table 7.6 Capacity regression Variables Entered/Removed[a]

Model	Variables Entered	Variables Removed	Method
1	av, F/D, img_t, P/F, x-ray_t[b]	.	Enter

a. Dependent Variable: Cap
b. All requested variables entered.

The overall model fitness accuracy is described in the model summary in Table 7.7. Column R shows the capability to calculate the output prediction using the predictor. The square of R column is to offer a more accurate reading of that measure by showing the alteration of the predictor. The standard error estimate column points out the amount that R fluctuates from one trial to the next trial.

Table 7.7 Capacity regression Model Summary[a]

Model	R	R Squared	Adjusted R Squared	Std. Error of the Estimate
1	0.840[a]	0.706	0.700	0.0589584

a. Predictors: (Constant), av, F/D, img_t, P/F, x-ray_t

The "**R**" column shows *R,* the multiple correlation coefficients. *R* can be treated as one measure of the quality of the estimation of the capacity variable as a dependent variable. A value of 0.840 points to a good level of prediction. The "**R Squared**" column shows the R^2 value (also named the determination coefficient), which is the ratio of variance in the predicted variable that can be clarified by the predictors (in theory, it is the ratio of variation calculated by the capacity regression model and beyond the mean model). It can be observed from the value of 0.706 that the predictors describe 70.6% as the variability of the capacity variable as a dependent variable. Nonetheless, it is necessary to calculate and understand "**Adjusted R Square**" or (*adj.* R^2) to accurately report on the given data (statistics.laerd.com, n.d.).

The *F*-ratio in the **ANOVA** shown in Table 7.8 checks whether the whole regression representation is appropriate for the data. The table illustrates that the predictors statistically significantly predict the capacity variable, $F(5, 242) = 116.016$, $p < .0005$ (i.e., the equation gained from the regression is a good fit of the collected data).

Table 7.8 Capacity regression ANOVA[a]

Model		Sum of Squares	df	Mean Square	F	Sig.
1	Regression	2.016	5	0.403	116.016	0.000[b]
	Residual	0.841	242	0.003		
	Total	2.858	247			

a. Dependent Variable: Cap
b. Predictors: (Constant), av, F/D, img_t, P/F, x-ray_t

The general form of the equation to predict capacity can be driven by knowing the regression variables av%, F/D, img_t and x-ray_t. This is gained from the **Coefficients**, as shown in Table 7.9. The table offers information on each predictor variable. It can be observed that all predictors and the constant contribute significantly to the regression as the **Sig.** column indicates. The **B** column under the **Unstandardized Coefficients** column indicates that it can be represented as the following equation:

$$\mathrm{Cap} = 1.013 - 0.001\times \mathrm{F/D} - 0.001\times \mathrm{P/F} - 0.005\times \mathrm{img\_t} - 0.04\times \mathrm{xray\_t} + 0.001\times \mathrm{av} \quad (7.2)$$

Unstandardized coefficients show how much the capacity varies with a predictor, when all predictors are kept constant. Looking at the impact of F/D in this equation, the unstandardized coefficient, B_1, for F/D is equal to -0.001 (see Table 7.9). This indicates that each unit increase in F/D leads to a decrease in cap with a value of 0.001 passengers/t. The statistical significance of each of the independent variables can be examined. This checks whether the coefficients are equal to 0 in the whole sample. If $p < 0.05$, it can be said that the coefficients are significant. The *t*-value and *p*-value are found in the "**t**" and "**Sig.**" columns respectively, as presented in Table 7.9.

Table 7.9 Capacity regression Coefficients[a]

Model		Unstandardized Coefficients		Standardized Coefficients	t	Sig.
		B	Std. Error	Beta		
1	(Constant)	1.013	0.027		38.054	0.000
	F/D	-0.001	0.000	-0.193	-4.549	0.000
	P/F	-0.001	0.000	-0.299	-7.566	0.000
	img_t	-0.005	0.001	-0.155	-4.084	0.000
	x-ray_t	-0.043	0.002	-0.802	-19.408	0.000
	Av	0.001	0.000	0.362	9.605	0.000

a. Dependent Variable: Cap

7.3.3 Disposed passengers regression

To develop a regression model of the disposed passengers predictors, the independents variables used in the regression are identified as shown in Table 7.10.The variables are av%, F/D, img_t and x-ray_t.

Table 7.10 Disposed passengers regression Variables Entered/Removed[a]

Model	Variables Entered	Variables Removed	Method
1	av, F/D, img_t, P/F, x-ray_t	.	Enter

a. Dependent Variable: Disp_pax

b. All requested variables entered.

Then an overview of model capability and precision is illustrated in Table 7.11. Column R examines the capability to calculate the output estimation via the independent variables. The R value here is 0.797, which reflects a high correlation. The square of R column indicates the precise interpretation of that measure by presenting the variation of the independent variables. It can be clarified by the predictors, "(Constant), av, F/D, img_t, P/F, x-ray_t ". In this case, R Squared is 63.5%, which can be considered as more than average. The standard error of the estimate column shows the extent of R fluctuation from the sample and the next one. It is equal to 2607.820 which is a high value due to the high number of passengers.

Table 7.11 Disposed passengers regression Model Summary

Model	R	R Squared	Adjusted R Squared	Std. Error of the Estimate
1	0.797[a]	0.635	0.627	2607.820

a. Predictors: (Constant), av, F/D, img_t, P/F, x-ray_t

Table 7.12 reports the "F-statistic" for the regression representation. Regularly, regression tables offer both the statistical values and their correlated significance; the most significant correlations have 0.000 as a significance statistical value. The examination of significance for the F-statistic produces the probability that none of the predictors in the current model are correlated with the predicted value disp_pax other than what could be described as chance. Table 7.12 explains the F-test's significance statistic in the way described below:

“Significance statistic of the regression model's for the F-test shows that there is no chance of even one in 1,000 that the detected correlation among one or more of the predictors and the predicted variable is for the reason of random sampling error."

Table 7.12 Dispose passengers regression ANOVA[a]

Model		Sum of Squares	df	Mean Square	F	Sig.
1	Regression	2860855117.785	5	572171023.557	84.134	0.000[b]
	Residual	1645775555.811	242	6800725.437		
	Total	4506630673.597	247			

a. Dependent Variable: Disp_pax
b. Predictors: (Constant), av, F/D, img_t, P/F, x-ray_t

Table 7.14 presents both unstandardized (B) and standardized (Beta) regression coefficients for each predictor in the regression and examines their significance for each of those statistics. The unstandardized constant (877.784 in Table 7.13) illustrates the value of the regression model predicted if all the predictors equal zero. The rest of the unstandardized regression coefficients (shown in column B) show that every F/D increase effects disp_pax with a 69.071 increment. P/F has a coefficient of 13.256 which represents the increment in disp_pax for increasing P/F by one. The same can be said for the coefficient of av which equals 13.900. The rest have a negative impact, img_t for example has a coefficient value of -334.567, which means that for every increment of one in img_t, the value of the predicted disp_pax decreases by -334.567; the same can be said about x-ray_t with a coefficient value of -422.442.

The standard deviation impact of each predictor on disp_pax variable shown in the "Beta" column is found in the standardized coefficients (see Table 7.13). Direct strength comparison is gained from the listed standardized measures among the predictors, which is the main use of this column. F/D is by far the most significant predictor of disp_pax, followed by img_t then x-ray_t but with a negative impact. After that P/F and finally av have a very limited effect on disp_pax with standard deviation value of 0.091.

Finally, the significance statistic for each predictor is tested as shown in the Sig. column in Table 7.13. Due to the limited sample size used, the issue of the data's reliability is raised. The statistical test checks the likelihood that a fluctuation in a specified predictor for a partial regression coefficient is a result of an error in sampling or not.

Precisely, it examines the probability that for a bigger sample beyond the sample currently used, there might be an increase in the predictor which has either no effect on disp_pax as a dependent variable or has a negative correlation. The pure chance as product of a random sampling issue or not the correlation found between different variables and disp_pax that can justify the case of av, over 3 percent of the time another sample could be expected to show either no relationship or a negative relationship with disp_pax as seen in Table 7.13, the correlation is positive (acme.highpoint.edu, n.d.).

Table 7.13 Disposed passengers regression Coefficients[a]

Model		Unstandardized Coefficients		Standardized Coefficients	T	Sig.
		B	Std. Error	Beta		
1	(Constant)	877.784	1177.076		.746	0.457
	F/D	69.071	5.427	0.601	12.726	0.000
	P/F	13.256	3.110	0.188	4.262	0.000
	img_t	-334.567	58.749	-0.241	-5.695	0.000
	x-ray_t	-422.442	96.926	-0.201	-4.358	0.000
	av	13.900	6.408	0.091	2.169	0.031

a. Dependent Variable: disp_pax

7.3.4 Total number of passengers regression

As suggested in the previous dependent variables, a regression model was carried out to obtain a prediction equation for the total number of passengers. The regression input and output can be identified as presented in Table 7.14 which reports Variables Entered/Removed. The predictors are av%, F/D, img_t and x-ray_t used to produce the regression equation.

Table 7.14 Total number of passengers regression Variables Entered/Removed[a]

Model	Variables Entered	Variables Removed	Method
1	av, F/D, img_t, P/F, x-ray_t[b]	.	Enter

a. Dependent Variable: Total_pax_no
b. All requested variables entered.

A summary of the model is shown in Table 7.15. The R value here is 0.808, which reveals a high level of correlation. The square of R indicates 65.3% which can be considered above average. The standard error estimate column shows the extent of R variation from a sample and the next one. It is 2592.818 which is large figure as the number of passengers is very high.

Table 7.15 Total number of passengers regression Model Summary

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate
1	0.808[a]	0.653	0.646	2592.818

a. Predictors: (Constant), av, F/D, img_t, P/F, x-ray_t

After that, analysis of variance is carried out using ANOVA "F-statistic" for the regression representation. Mainly, regression tables propose both the statistical values and their significance, with 0.000 being the most significant value. The relationship between those variables (dependent and independent) is illustrated as a straight line as it is a linear regression.

Table 7.16 Total number of passengers regression ANOVA[a]

Model		Sum of Squares	df	Mean Square	F	Sig.
1	Regression	3065678414.388	5	613135682.878	91.204	.000[b]
	Residual	1626894043.285	242	6722702.658		
	Total	4692572457.673	247			

a. Dependent Variable: total_pax_no
b. Predictors: (Constant), av, F/D, img_t, P/F, x-ray_t

Finally, the general form of the equation is carried out to predict the total number of passengers by entering regression variables of av%, F/D, img_t and x-ray_t. This is shown in the **Coefficients** table, as reported in Table 7.17. The table reveals details for every predictor variable. It can be said that most predictors contribute significantly to the regression as the **Sig.** column indicates, except the constant and the av. The **B** column under the **Unstandardized Coefficients** column specifies that it can be modelled in the following equation:

$$Cap = 647.788 + 77.237 \times FD + 17.053 \times PF - 320.165 \times img\_t - 314.865 \times x\_ray\_t + 6.604 \times av \quad (7.3)$$

Unstandardized coefficients illustrate the total number of passenger's variation response with a predictor, when all other predictors are kept unchanged. For example the impact of F/D in this equation, the unstandardized coefficient, B_1, for F/D is equal to 77.237 (see Table 7.17). This indicates that for each 1 increase in F/D, there is an increase in the total number of passengers of 77.237. The statistical significance of each of the independent variables can be examined. This checks whether the coefficients are equal to 0 in the whole sample. If $p < 0.05$, it can be said that the coefficients are significant.

The standard deviation impact of each predictor on the disp_pax variable are shown in the "Beta" column found in the standardized coefficients (see Table 7.17). A direct strength comparison is gained from the listed standardized measures among the predictors, which is the main use of this column. F/D is by far the most significant predictor of disp_pax, followed by img_t then x-ray_t but with a negative impact. After that, av and finally av can have a very limited effect on the total number of passengers with a standard deviation value of 0.042. Finally, the significance statistic for each predictor should be tested which is shown in Sig. column in Table 7.18 below. Due to the limited sample size, the issue of reliability is raised. The statistical test checks the likelihood that a fluctuation in a specified predictor for a partial regression coefficient is a result of error in sampling or not.

Table 7.17 Total number of passengers regression Coefficients[a]

Model		Unstandardized Coefficients		Standardized Coefficients	t	Sig.
		B	Std. Error	Beta		
1	(Constant)	647.788	1170.304		.554	0.580
	F/D	77.237	5.396	0.658	14.313	0.000
	P/F	17.053	3.092	0.237	5.515	0.000
	img_t	-320.165	58.411	-0.226	-5.481	0.000
	x-ray_t	-314.865	96.368	-0.146	-3.267	0.001
	av	6.604	6.371	0.042	1.036	0.301

a. Dependent Variable: total_pax_no

7.3.5 Linear regression evaluation

Regression equations for pax_t, cap, disp_pax and total_pax_no are produced, and a comparison study is conducted to evaluate the accuracy of each equation. The set of executed trials contains 248 scenarios, with results available for each one. Those results are considered as the actual value of each dependent variable. A series of 248 predictions for each dependent variable is carried out. Then, the error ratio is calculated for each reading to get an average of the total readings. A sample of five readings is reported with the error ratio (as shown in Table 7.18).

Table 7.18 Linear regression actual and predicted values for a sample

Actual				*Predicted*				*Error*			
Pax_t	Cap	Disp	Total	Pax_t	Cap	Disp	Total	Pax_t	Cap	Disp	Total
131.4	0.840	4311	5133	88.5	0.704	6679	7308	0.326	0.162	0.550	0.424
88.5	0.884	4249	4806	98.2	0.694	6540	7242	0.110	0.216	0.539	0.507
118.0	0.849	4188	4931	108.0	0.684	6401	7176	0.085	0.195	0.529	0.455
166.1	0.789	4063	5151	117.7	0.674	6262	7110	0.291	0.146	0.541	0.380
115.5	0.857	4345	5070	127.4	0.664	6123	7044	0.103	0.226	0.409	0.390

For each variable an x-y plot is prepared with actual value of the variable on the x-axis and the predicted value on the y-axis. In an ideal case, this should create a straight line with an angle of 45°. The first plotting shown in Figure 7.1 indicates fluctuation and the highest estimated value found is 750 and the lowest is 8.14 while the actual values have highest value of 723.96 and lowest of 23.97. The graph shows points registered far from the straight line and the plot with the sample data shows heteroscedasticity.

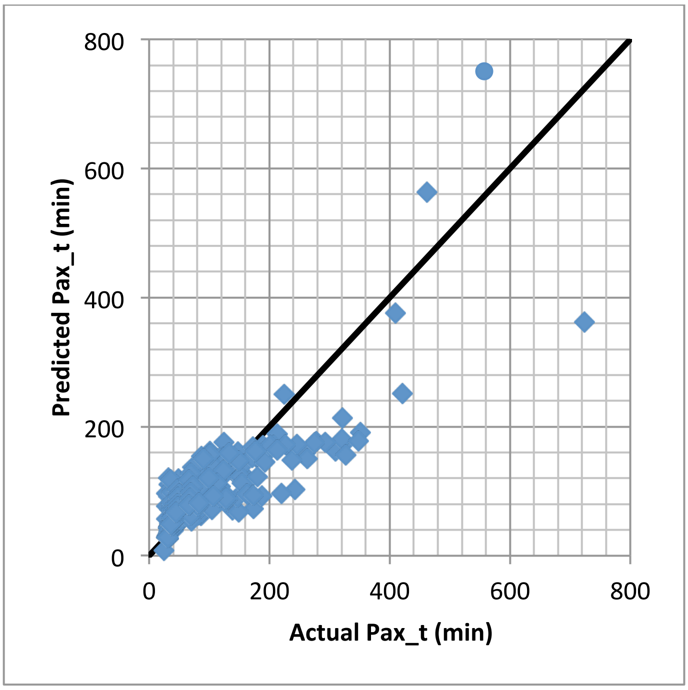


Figure 7.1 Passenger time predicated from FIS across the actual value (Heteroscedasticity)

The next variable is cap where its values are constrained to between 0 and 1 as it is a ratio of the number of passengers disposed from the system to the total number of passengers. The highest actual value is 0.99 and the lowest is 0.23. On the other hand, the highest predicted value is 0.93 and the lowest is 0.03. The accuracy increases as cap is increased as shown in Figure 7.2. There is some randomness that increases the error ratio which will be discussed later in this chapter.

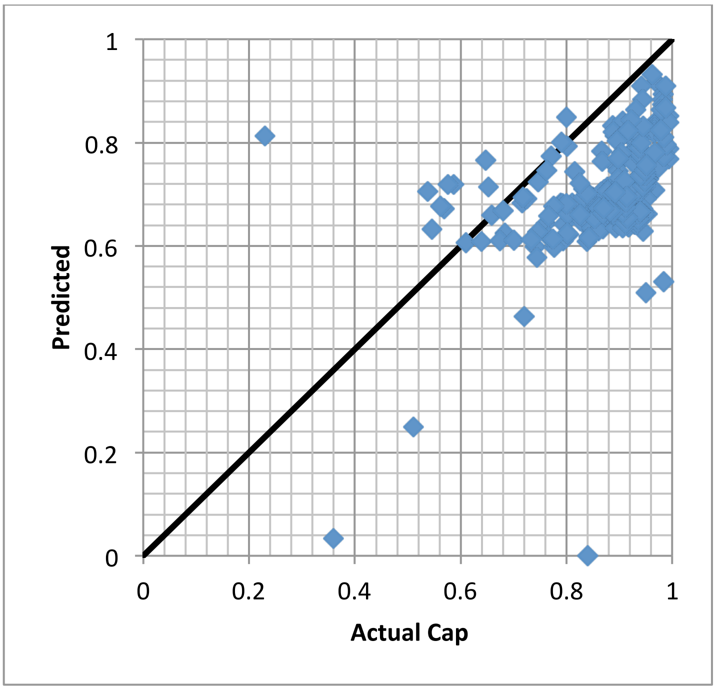


Figure 7.2 Capacity ratio predicated from FIS across the actual value

Disp_pax, plotted as shown in Figure 7.3, achieved a clearer straight line between 5000 and 17000, although it fluctuates below 5000 and above 17000. There are a couple of negative predicted values which are considered unrealistic. The highest predicted value is 15676.42 and the lowest is 2897.43 with a negative value. On the other hand, the highest actual value registered is 17544.3 and the lowest actual value is 1507.5. The fluctuation appeared clearly in the graph which indicates a high error ratio (see Figure 7.3).

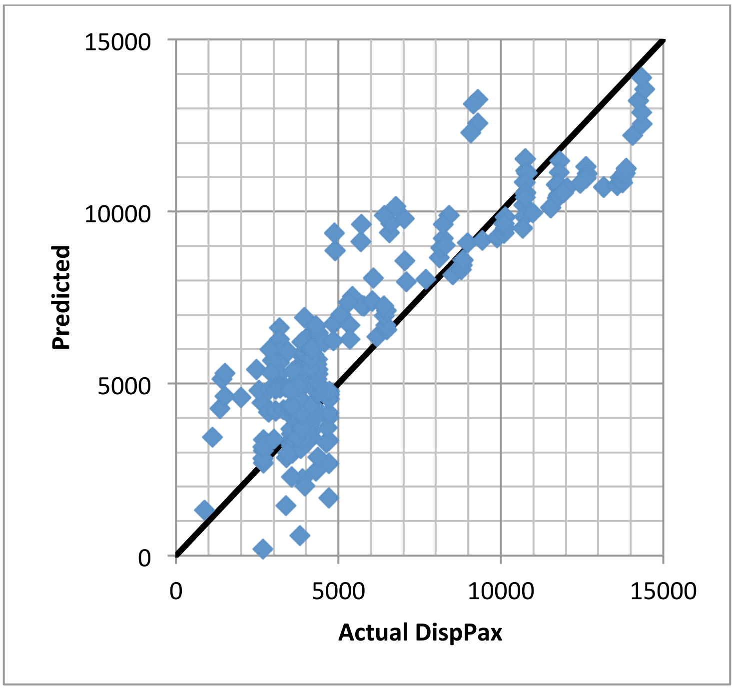


Figure 7.3 Disposed passenger number predicated from FIS across the actual value

Lastly, a similar behaviour is seen with total passenger number shown in Figure 7.4 as it fluctuates between 0 and 5000 and is sort of steady above 5000 yet some randomness is observed after 17500. The highest predicted value measured is 16923.11 while the lowest predicted is -817.35. On the other hand the highest actual reading is 18133.64 and the lowest actual registered is 1507.5 which shows some fluctuation form the ideal case which affects the error ratio.

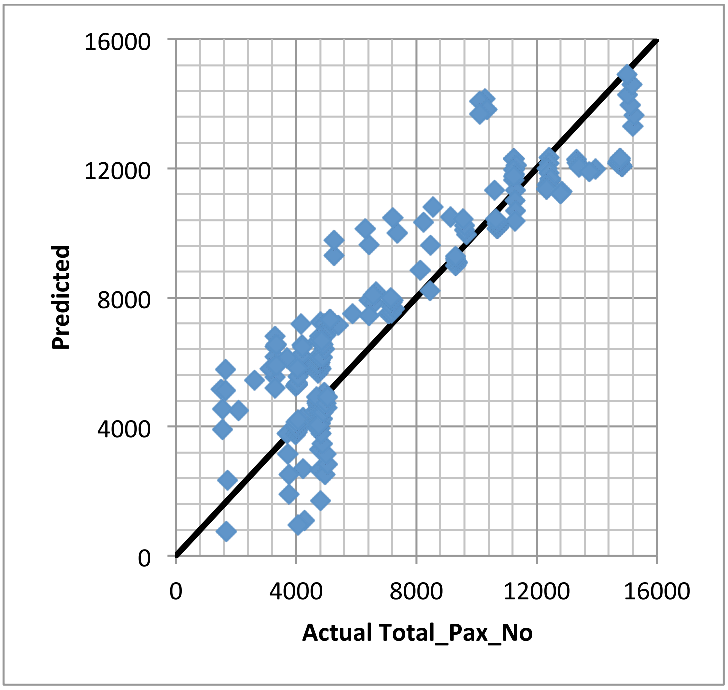


Figure 7.4 Total Passenger Number predicated from FIS across the actual value

The highest error ratio found with the dependent variable of pax_t is 38%, while the lowest error registered on the cap variable is 19%. Disp_pax registers an error ratio of 36% and total_pax_no has an error value equal to 28% (see Table 7.19).

Table 7.19 Linear regression Error ratio

Pax_t	*Cap*	*Disp_pax*	*Total_pax_no*
0.381827	0.188855	0.356032	0.282994

This leads to the conclusion that a higher accuracy model is required which can be achieved by Levenberg–Marquardt algorithm to fit the regression equation.

7.4 Levenberg-Marquardt regression algorithm

The Levenberg–Marquardt algorithm (LMA), identified as the damped least-squares (DLS) technique, is considered to explain non-linear results with least squares problems and this is done by least square curve fitting. The Levenberg–Marquardt algorithm combines the use of the Gauss Newton algorithm GNA with the technique of gradient descent.

The error ratio seen earlier in the linear regression model is motivation to find another fitting algorithm. Here the Levenberg-Marquardt regression algorithm used in matlab as four functions is created. First, the load command extracts the whole table as a data set then inputs are extracted into a matrix variable of five inputs called x-data. After that, another matrix is assigned to contain the output of the dependent variable named y-data. Then, a variable matrix is defined for holding the coefficient values and initialising with zero value. Next, the boundaries of the search are assigned in matrices called MaxValue and MinValue. Then options related to optimisation, iteration level and Levenberg-Marquardt option are set. This is to prepare executing the curve fitting function "lsqcurvefit" then plotting and printing the parameters (see Figure 7.5).

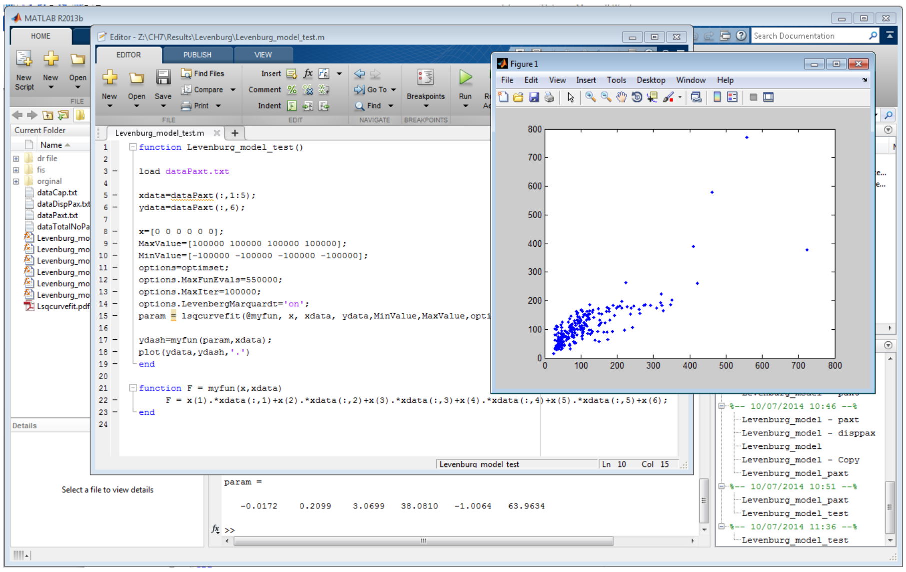


Figure 7.5 Running Levenberg-Marquardt regression algorithm

After executing the code with different settings, good results were experienced over wide ranges of selection, with 1000 for the MaxValue and -1000 for the MinValue. The coefficients are presented in Table 7.20.

Table 7.20 Levenberg-Marquardt regression coefficients

(LMA reg.)	*pax_t*	*disp*	*cap*	*total_pax_no*
(Constant)	63.9634	134.105	0.9899	-29.811
F/D	-0.0172	74.4124	-0.0003	81.8255
P/F	0.2099	14.225	-0.0005	17.9417
img t	3.0699	-327.13	-0.0061	-310.88
xray t	38.081	-299.11	-0.0421	-194.86
%av	-1.0064	13.7058	0.0014	6.3378

Firstly the pax_t shows high similarity with the linear regression plot, although with different parameters values as reported in Table 7.20. As pax_t increases, the gap becomes wider between the predicted and the actual reading, while capacity shows a more accurate prediction as the fluctuation is lower than that observed in the linear regression. Both disp_pax and total_pax_no show similar three zone plots as shown earlier in the linear regression. The first zone is between zero and 5000, which shows a high level of randomness then it moves to a linear zone between 5000 to 17500, and lastly some randomness is observed above 17500 (see Figure 7.6 - Figure 7.9).

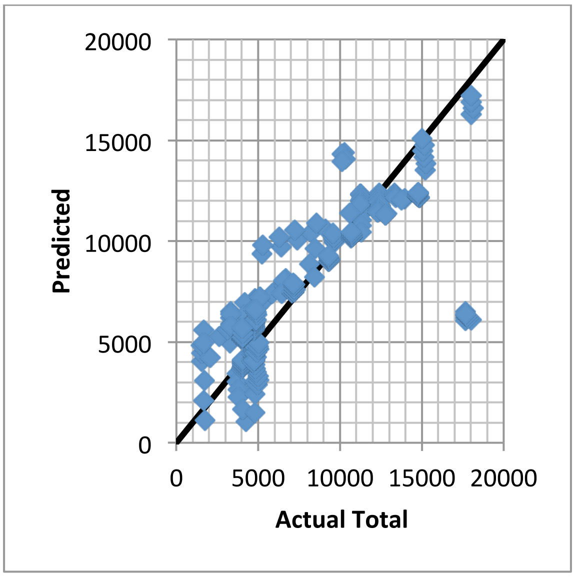


Figure 7.6 Total passengers predicted from FIS across the actual value

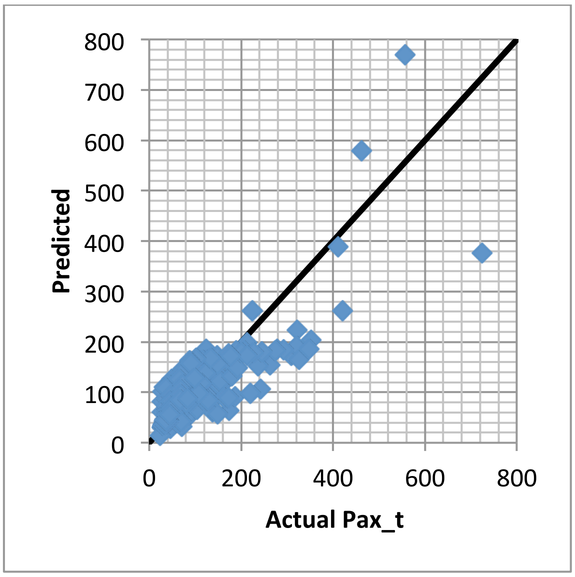


Figure 7.7 Passenger time predicted from FIS across the actual value (Heteroscedasticity)

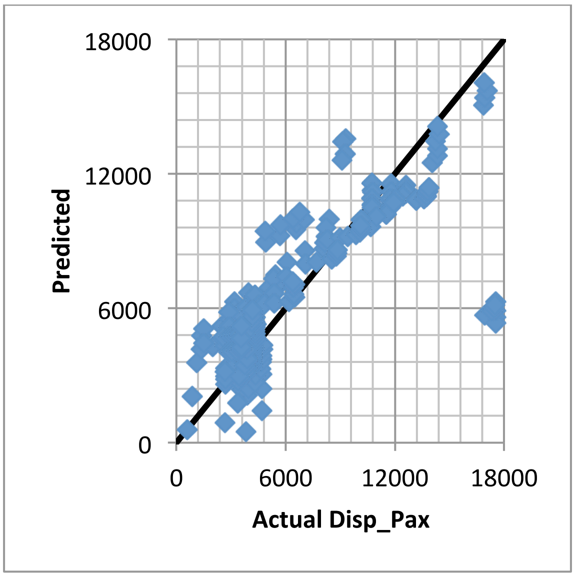


Figure 7.8 Disposed passengers predicted from FIS across the actual value

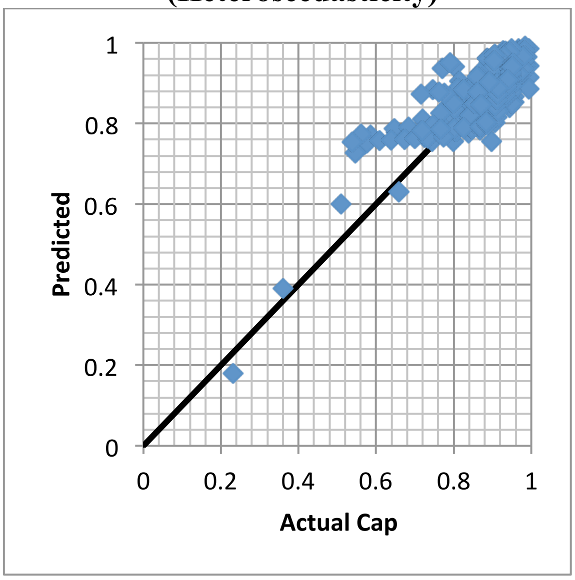


Figure 7.9 Capacity predicted from FIS across the actual value

It can be seen that a tool which is more efficient for modelling and predicting the dependent variables is needed. The Adaptive Neuro Fuzzy Inference System (ANFIS) can be seen in the next section for that purpose.

```
Levenburg_model_paxt.m
function Levenburg_model_paxt()

load dataPaxt.txt

xdata=dataPaxt(:,1:5);
ydata=dataPaxt(:,6);

x=[0 0 0 0 0 0];
MaxValue=[10000 10000 10000 10000];
MinValue=[-10000 -10000 -10000 -10000];
options=optimset;
options.MaxFunEvals=550000;
options.MaxIter=100000;
options.LevenbergMarquardt='on';
param = lsqcurvefit(@myfun, x, xdata, ydata,MinValue,MaxValue,options)

ydash=myfun(param,xdata);
plot(ydata,ydash,'.')
end

function F = myfun(x,xdata)
    F = x(1).*xdata(:,1)+x(2).*xdata(:,2)+x(3).*xdata(:,3)+x(4).*xdata(:,4)+x(5).*xdata(:,5)+x(6);
end
```

Figure 7.10 Levenberg-Marquardt regression algorithm

7.5 Adaptive neuro fuzzy inference system modelling

Neuro-Fuzzy (NF) is known as an integration of neural networks and fuzzy logic (Jang, 1993). Self-learning is an element that is used by processing data samples to save or its fuzzy sets and fuzzy rules. A NF system is defined as a fuzzy system which employs a self-learning algorithm derived and inspired by neural network concepts to achieve its fuzzy sets and fuzzy rules using processing data samples (Al-Kanhal, 2010). In this section, simulation scenarios' results data is used to develop the NF system that models the airport performance factors, such as the number of disposed passengers and total passenger time, as a 'FIS' fuzzy inference system file. The hybrid system called ANFIS associates the verbal rule of fuzzy logic using the numeric control of neural systems for each dependent variable. As is recognized from the philosophy of fuzzy systems, diverse fuzzification and defuzzification techniques with diverse rule arrangements suggest many solutions to a certain problem; the chosen solution is tested with the actual reading. The Matlab "anfisedit" command called ANFIS Editor GUI allows the user to load training data from the file prepared earlier, then generate a FIS file which can be called to estimate or predict a dependent variable. The FIS file is generated using a grid partition option and the hybrid train optimisation method is selected with the default epochs value of 3. The test is used on the trained data to gain a plot of the tested training data. Next a surface is created to illustrate the relationship of each input with the output as shown in Figure 7.11 and 7.12. This checks how reasonable the output is, and identifies the boundary of each independent. The Gaussian combination membership function is selected to perform the model with 3 MF for each input as shown in Figure 7.13.

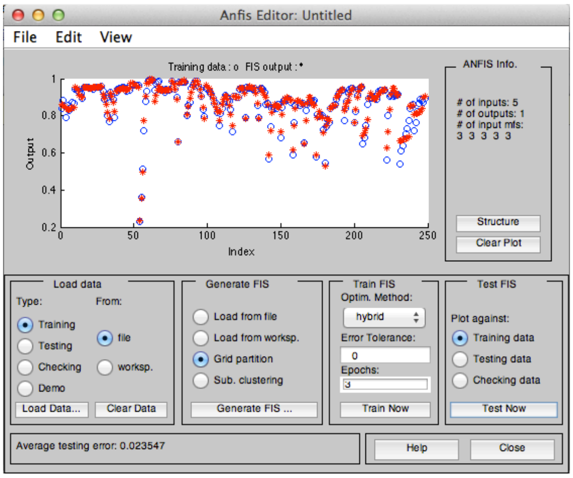


Figure 7.11 Anfis Editor Settings

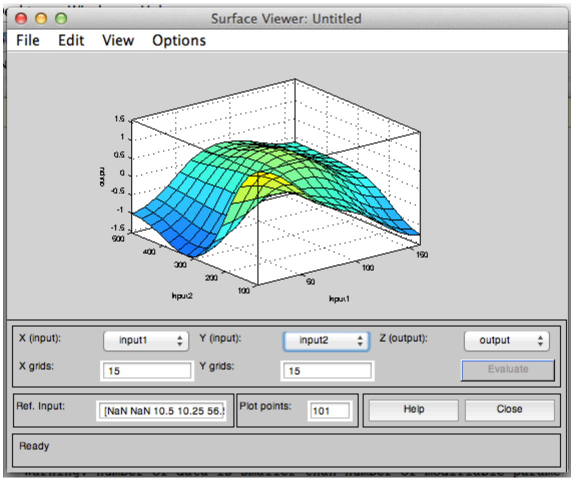


Figure 7.12 Surface Viewer for two inputs

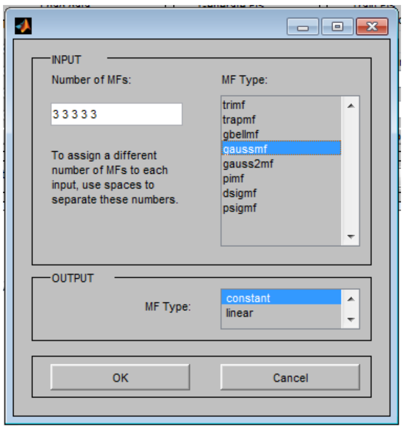


Figure 7.13 MF type of Anfis inputs and outputs options

```
clear all
close all
load datatotalnopax.txt
```

```
xtotal=datatotalnopax(:,1:5);
ytotal=datatotalnopax(:,6);
fistotal= readfis('fistotalnopax') ;
for i=1:253
ytotal3(i)= evalfis(xtotal(i,:),fistotal);
end
ytotal2=ytotal3';
figure(1)
RESULTS=[ytotal(:,1) , ytotal2(:,1)];
```

Figure 7.14 code used to plot each dependent value with the predicted value

The matlab code shown in Figure 7.14 is used to plot each dependent value with the predicted value using the generated FIS file. First the raw input output files are loaded then the input is imported as a matrix with five columns. After that the actual output is stored in an array then the dependent FIS file loaded with "readfis". Then each trial output is predicted from the FIS file and stored in another array in order to compare it with the actual reading; finally plots are generated (see Figure 7.15 - Figure 7.18).

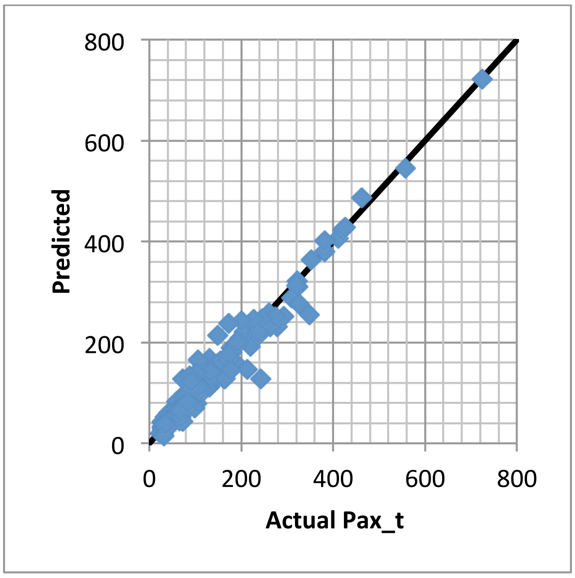


Figure 7.15 Passenger time predicted from FIS across the actual value (with homoscedasticity)

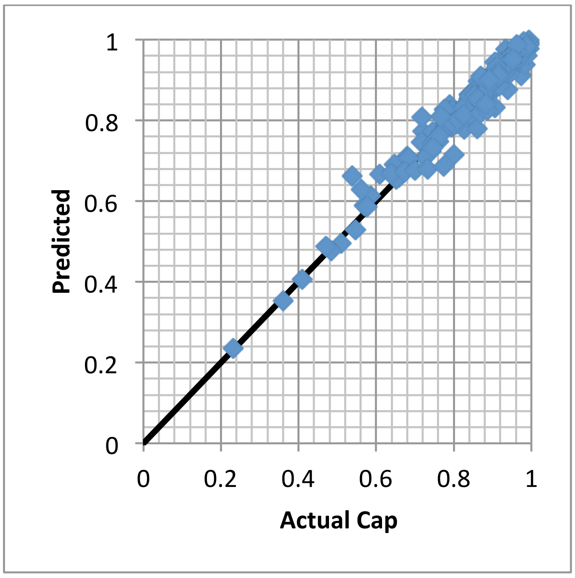


Figure 7.16 Capacity predicted from FIS across the actual value (with homoscedasticity)

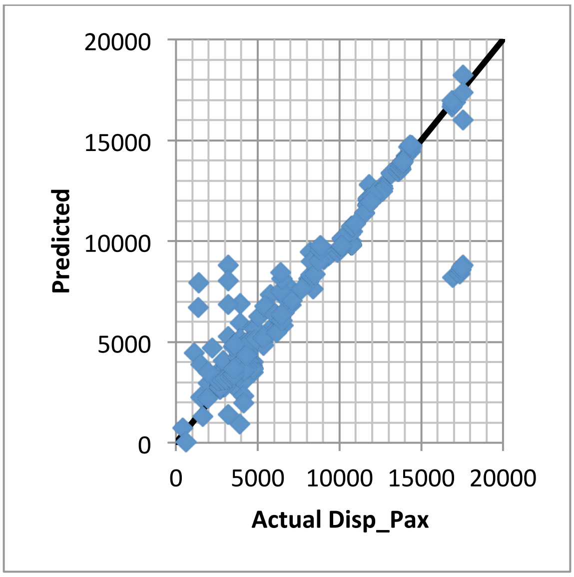


Figure 7.17 Disposed passengers predicted from FIS across the actual value (with homoscedasticity)

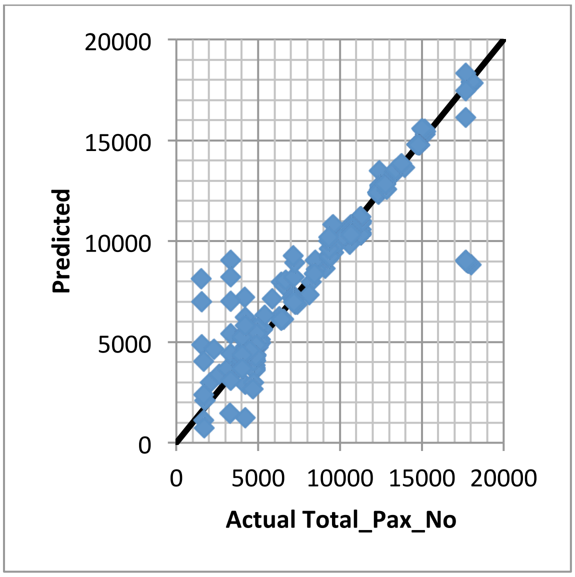


Figure 7.18 Total passengers predicted from FIS across the actual value (with homoscedasticity)

7.6 Optimisation

Optimisation strategies are characterized as the "experience-based" routines that assist in making decisions and learning (Pearl, 1984) and the meaning of a metaheuristic is a group of algorithmic ideas that could be utilized to characterize heuristic techniques pertinent to a wide set of distinctive issues. As such, a metaheuristic is a universally useful algorithmic structure that could be connected to diverse improvement issues with generally few alterations (Dorigo et al., 2006). Artificial intelligent strategies, for example NF that is specified in this section, are metaheuristic techniques and additionally the wise streamlining methods are formalized as optimisation procedures. Two main contributions are deployed in this section by using GA and PSO after normalisation is carried out.

7.6.1 Normalisation

Normalisation is the process of converting all variables in the data to a definite range. In data mining approaches it is used to create conditions where it can guarantee stable convergence of weight and biases. Each reading is subtracted by the mean and then divided by the standard deviation. Brief details needed for normalisation are reported in Table 7.21 which is used in the optimisation stage.

Table 7.21 Brief details needed for normalisation

	total	*Pax_t*	*disp*	*cap*
avg	7585.582	105.9931	6777.043	0.871876
max	18785.91	722.1666	18674.99	0.998169
min	667.1155	14.61412	260.5118	0.234595
stand dev	4014.922	89.98966	3920.368	0.104441

7.6.2 PSO optimisation

Matlab is used to carry out PSO optimisation as it reads all four dependent FIS files that are created by ANFIS as seen earlier. The number of parameters 'N_par' is assigned to 5. The number of particles is set to 'N=100' then the boundary of change is assigned to insure that the particles' parameters do not go to an undefined range not covered by the FIS file while 'c1 = 1.49618', 'c2 = 1.49618', 'w = 0.7298' and the number of iteration is set to Nit = 100 as Eberhart and Shi (2000) confirmed that an inertia weight of 0.7298 and acceleration coefficients of 1.49618 are good parameter choices, leading to convergent trajectories.

Then the PSO algorithm is applied to get local and global best particles. Finally parameters are revealed. During the exclusion of the PSO optimisation each answer to the cost function is illustrated in a plot diagram that reveals how each time a more appropriate solution is carried out and monitored in the graph shown in Figure 7.19.

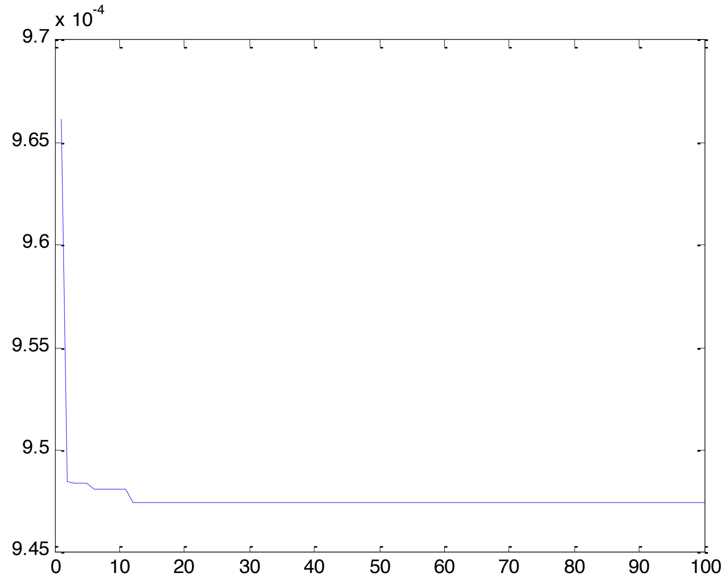


Figure 7.19 Cost function values plotted during PSO

7.6.2.1 PSO Verification

After executing the code (see Appendix D) many times with different cost functions and different applicable ranges, a set of output-predicted and actual values needs to be checked and verified in order to examine the fuzzy logic's accuracy. The first set of PSO answers are gathered and each one entered into a FIS file to get the predicted value for the four output variables. Then the Arena model is used to compare that predicted value by having the parameter as the input to the model. There are cases where the inputs are not valid, mainly for two reasons: either the data is undefined in the generated FIS or Arena cannot run that combination of parameters and both reasons can relate to each other. For example if a combination of parameters can cause error that leads to them not having a value that can be entered and considered in the FIS file.

Table 7.22 PSO Results Verification

Independent variables					*Arena*				*Predicted*			
F/D	**P/F**	**img_t**	**x-ray_t**	**av**	**disp**	**pax_t**	**total**	**cap**	**disp**	**pax_t**	**total**	**cap**
17	170	1.5	1.5	100	1449	47	1537	0.94275	5681.34	48.06	5808.31	0.97
144	222	1	0.5	100	15604	38	16460	0.948	16023	42.54	17032.6	0.94
90	250	3	0.5	70	11033	37	11615	0.94989	9312.63	124.44	11091.3	0.83
32	255	4.5	2	88	3641	132	4421	0.82357	5730.77	116.82	6405.45	0.86
30	150	3	1.5	100	2223	48	2373	0.93679	4583.5	46.15	4697.77	0.97
77	290	3	1	93	9749	134	11919	0.81794	10919.3	132.14	12655.4	0.83
110	230	4.5	0.5	75	12366	40	13074	0.94585	13246.2	7.5	13511	0.99
18	160	1	1.5	98	1445	45	1529	0.94506	5294.68	43.08	5369.27	0.98
140	240	0.5	0.5	97	16411	42	17399	0.94322	15309	27.01	16430.1	0.93
37	248	3.5	1	92	4487	55	4831	0.92879	7220.6	66.68	7617.68	0.93
79	277	1.5	0.5	89	10716	39	11297	0.94857	13140.8	109.96	14461.7	0.91
33	215	1.5	2	78	3308	103	3820	0.86597	4128.24	15.11	3645.11	1
32	130	0.5	1	90	2081	30	2159	0.96387	7544.53	2.62	7316.39	1.02
76	280	0.5	0.5	83	10446	36	10988	0.95067	11419	153.68	13401.2	0.84
19	170	1	0.5	88	1625	25	1710	0.95029	13658.5	18.46	13555.4	1.03

Initially, the actual total number of passengers is revealed with the estimation related outcome as is plotted in Figure 7.20 and the results are shown in Table 7.22 which has five independent variables generated from optimisation and then entered to both arena and the data driven model for comparison purposes. There is a good level of precision compared to other techniques of regression as fuzzy logic achieves a decent educated guess for the total number of passengers. The shortages can be found clearly after optimisation is carried out as the PSO optimiser tries to produce a massive number of repetitions that are used to compute more accurately the value of the cost function. That mainly forces it to generate points that were not covered in the prepared sample carried out in the results chapter. The optimisation might be done at various known intervals to eliminate that.

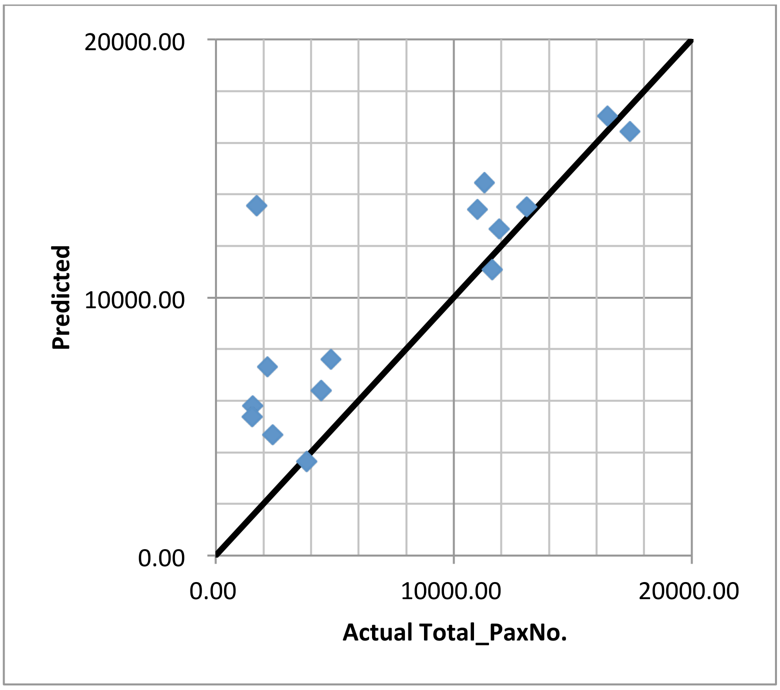


Figure 7.20 Obtained total number of passengers predicted across the actual value

The point (1537, 5808.31) is found to be the least accurate estimation as is illustrated in the plot diagram in Figure 7.20 that exposes all expected values with the actual outcomes gathered from the Arena results. All other predictions in the x-y graph have more precise estimations. The same plot is drawn for the passenger time as shown in Figure 7.21, where a higher level of chaos is found in the graph.

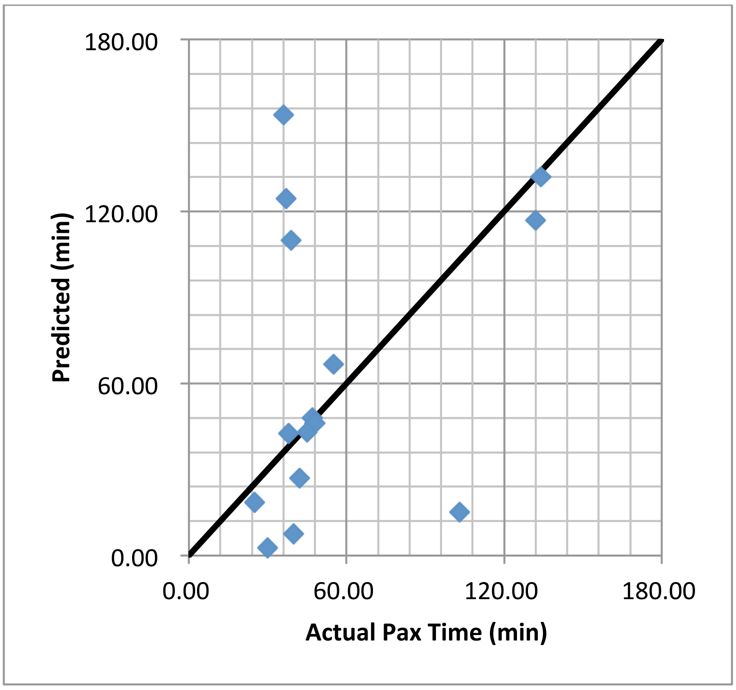


Figure 7.21 Obtained passenger time predicated from FIS across the actual value

The passenger time graph has a total number of four points far from ideal or optimal predictions - three of them greater than the supposed value and the fourth below the actual value. Other points show a decent level of linearity as they have a small level of fluctuation around the optimal prediction line. The next plot illustrates the actual disposed passenger number against its predicted value. From a first glance better prediction is shown in this dependent variable as shown in Figure 7.22.

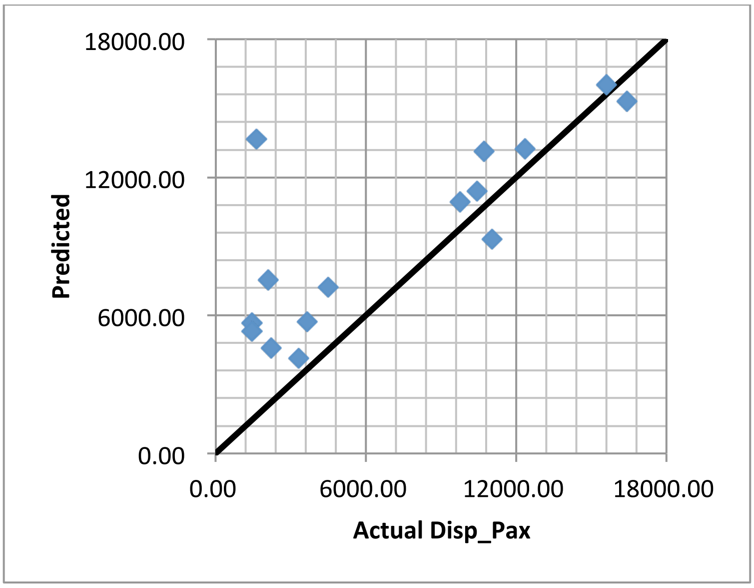


Figure 7.22 Obtained disposed passengers predicted from FIS across the actual value

The point (1625, 13658.5) stands away from the accurate prediction, clearly illustrated in the Figure 7.22. A medium fluctuation is observed among the other points, but they still revolve around the optimal line. There are some points which show very good level of accuracy like (15604, 16023) which clearly is not accomplished by the linear regression model.

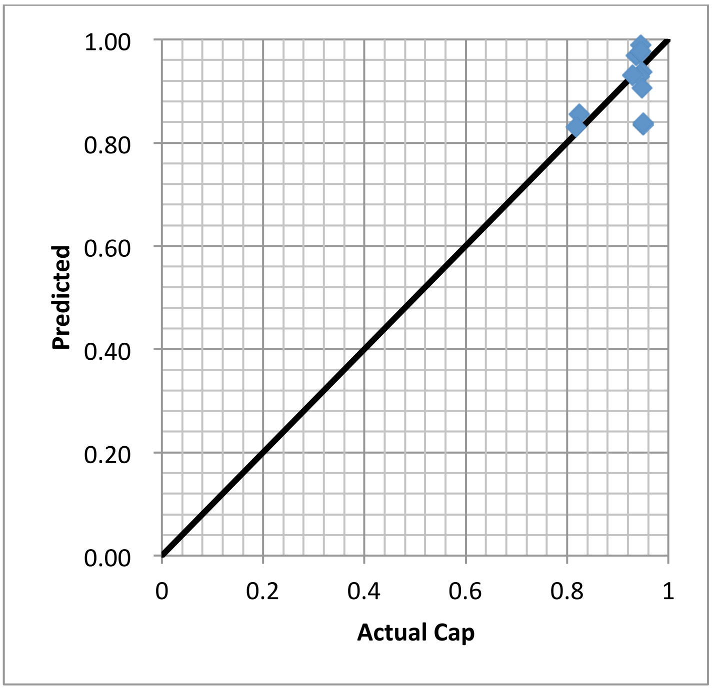


Figure 7.23 Obtained capacity predicted from FIS across the actual value

Capacity is a dependent variable, it fluctuates in actual readings from 0 to 1. Iin the context of airport terminals' operations, this variable would be as high as possible to attain high operation performance and that is shown in Figure 7.23 as it fluctuates between 0.8 and 1.

7.6.3 GA optimisation using Optimtool and Optimizationapp

The Optimtool called Optimizationapp selects the optimisation algorithm, or solver as it is known as, to optimise the function. That opens a GUI which can be fed with the function or the problem, the optimisation option and the solver. "The Optimization app can be used to run any Optimization Toolbox solver and any Global Optimization Toolbox solver except Global Search and MultiStart. Results can be exported to a file or to the MATLAB workspaces a structure”. First the solver is selected then the algorithm picked - in GA case there is only one available algorithm. After that a number of variables is entered (in this case 5), then lower and upper bounds are entered (mathworks.co.uk, n.d.). Function fitness will be used on the cost function which has been included. Lower and upper limits are set to the intervals that need to be searched as illustrated in Figure 7.24. Then the population type is set to be “double vector”, the population size is selected to be 20, the creation function option is set to “constraint dependent” and all other populations use the default settings. The second option category is related to “fitness scaling” and assigned to “rank” scaling function. The third category revolves around the selection where “stochastic uniform” is assigned as a selection function. The fourth category in the option is reproduction which used an elite count of “2” cross over fraction of “0.8”. The fifth category is a mutation function set to “constrain dependent”. Cross over is the sixth option category where “scattered” cross over function is used. Migrate category has “forward” as its direction setting where the fraction is set at “0.2” and the interval “20”. Constraint parameters have initial penalty of “10” and penalty factor of “100”. The hybrid function option category is set to be “none” hybrid function. Stopping criteria has “100” generations , “inf” ∞ or time limit, “-inf” or $-\infty$ fitness limit, stall generations is set to “50”, stall time limit is set to “inf”, function tolerance “1E-6” and nonlinear constraint tolerance used is “1E-6”.

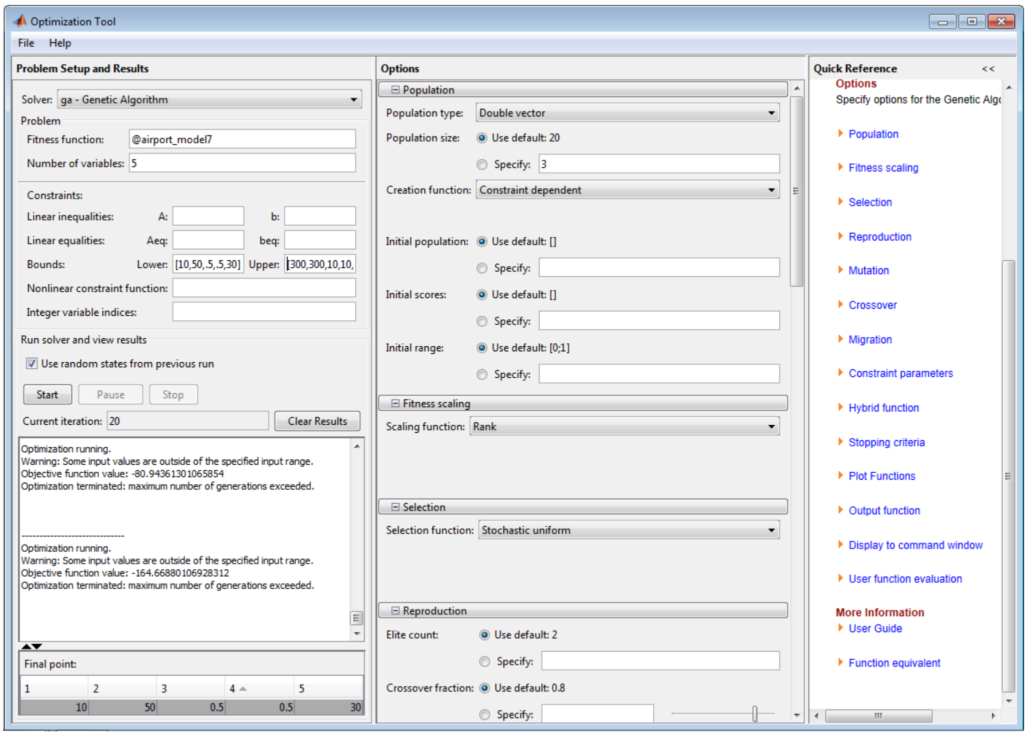


Figure 7.24 Optimization tool settings for GA optimisation

The function of the problem should be created and named in the optimtool which starts by reading the FIS using the ‘readfis’ command. A variable named Xp is used to store the random generated value of the iteration. Then the predicted values of the four dependent variables are used to create a cost_f after normalising the variables as shown in Figure 7.25.

```
function cost_f = airport_model7(Xp)

fistotal= readfis('fistotalnopax') ;
fisPax_t= readfis('fisPax_t');
fisdisp= readfis('fisDisp_pax') ;
fiscap= readfis('fiscap') ;

   Pax_t=evalfis(Xp,fisPax_t);
   total=evalfis(Xp,fistotal);
   cap=evalfis(Xp,fiscap);
   disp=evalfis(Xp,fisdisp);

                  %mean        %std
Pax_t=(Pax_t-105.9930602)/89.98965815;
total=(total-7585.582013)/4014.92155;
cap=(cap-0.871875856)/0.104441283;
disp=(disp-6777.042994)/3920.368309;

cost_f = (7*(1-Pax_t)+20*(total)+5*(cap)+2*(disp))/18;
```

Figure 7.25 Sample of cost function code used in GA optimisation

7.6.3.1 GA Verification

By running the “optimtool” many times with diverse cost functions and different appropriate ranges, a set of output-predicted and actual values need to be checked and verified to examine the fuzzy logic precision. Initially a set of GA solutions are collected and each one goes into a FIS file to get the predicted value for the four output variables. Then the Arena model is used to compare that estimated value by having the parameter as an input to the model. There were cases where inputs are not valid, mainly for the same reasons as stated in the PSO verification.

Table 7.23 GA Results Verification

Independent variables					*predicted*				*Arena*			
F/D	***P/F***	***Img_t***	***Xray***	***Av***	***Total***	***Pax_t***	***Disp***	***cap***	***Total***	***Pax***	***Disp***	***cap***
90	200	7	0.5	55	9323	175.2	7060	0.760	9294	172.8	7091	0.763
90	200	7	0.5	95.5	10142	36.9	9718	0.960	9299	37.8	8826	0.949
95	300	4	0.5	60	14767	71.4	13364	0.903	14834	74.7	13336	0.899
95	300	4	0.5	60	14767	71.4	13364	0.903	14834	74.7	13336	0.899
90	230	5	0.5	55	10840	127.2	8982	0.827	10744	73.3	9672	0.900
90	230	5	0.5	95.5	10329	37.7	9777	0.946	10685	36.5	10157	0.951
95	300	4	0.5	60	14767	71.4	13364	0.903	14834	74.7	13336	0.899
95	300	4	0.5	96	14784	43.6	13915	0.941	14941	54.8	13849	0.927
50	100	2.6	1	40	8593	156.7	7871	0.801	2592	29.8	2488	0.960
85	210	6	0.5	96	9333	28.1	8917	0.955	9220	35.1	8775	0.952
95	195	5	1	97	7328	91.0	6058	0.847	9801	95.6	8515	0.869

Firstly, the actual total number of passengers is plotted with the predicted associate result as it appeared in Figure 7.24 by taking values from Table 7.23. There is a high level of accuracy compared to other types of regressions as fuzzy logic performs a good estimation for the total number of passengers. The deficiencies can be found clearly after optimisation as the optimiser tries to generate an enormous number of iterations, used to calculate more accurately the value of the cost function. These force it to create points that were not covered in the sample prepared in the results chapter. To avoid that, optimisation might be carried out at various known intervals. The point (2592, 8593) is found to be the least correctly predicted, as can be seen in the plot diagram shown in Figure 7.24 that compares all predicted values with the actual readings found in the Arena report. Apart from that, all other estimations in the x-y plot have more accurate predictions. The same plot is carried out for the passenger time as shown in Figure 7.27 where better accuracy is shown.

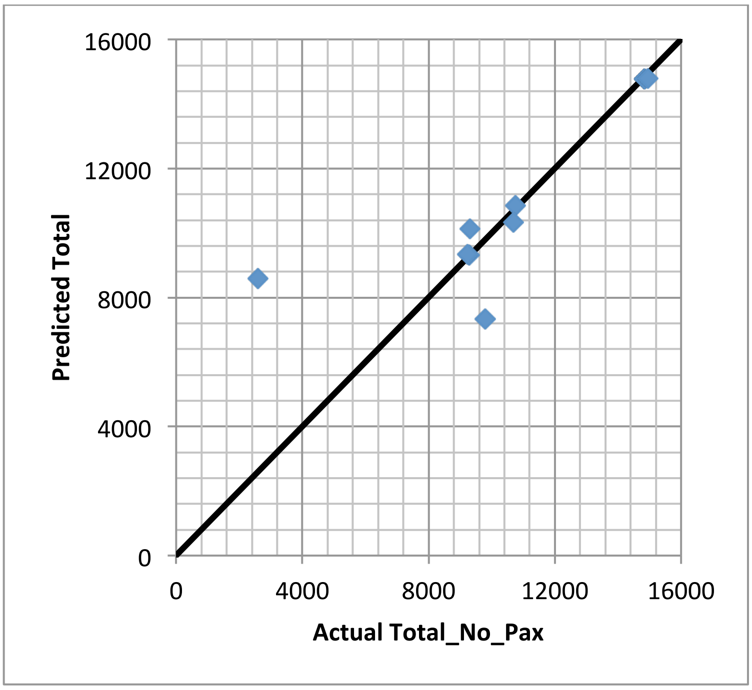


Figure 7.26 Obtained Total passengers predicted from FIS across the actual value

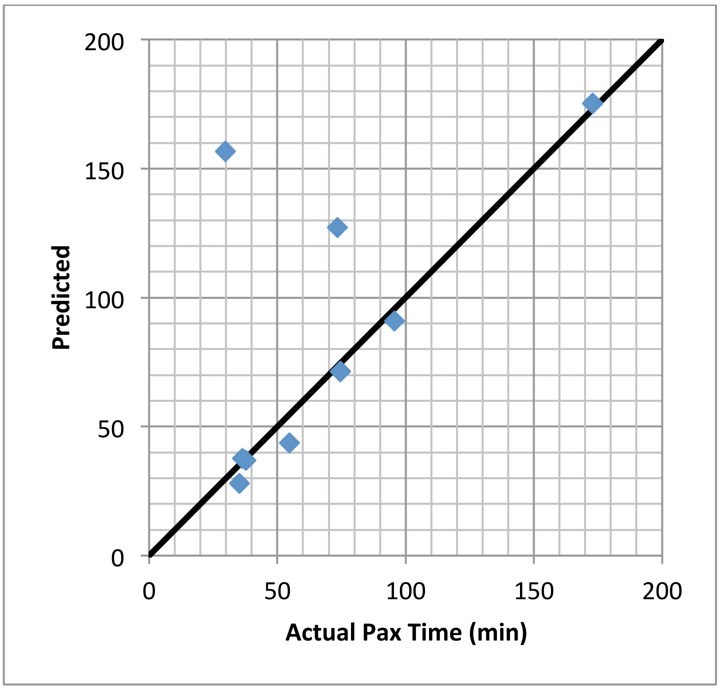


Figure 7.27 Obtained passenger time predicted from FIS across the actual value

The two following points (29.8, 156.7) and (73.3, 127.2) appear to be far from the optimal estimation of the actual passenger time as shown in Figure 7.27. Other than that, every other prediction is found to be highly well estimated. From another prospective, the points are more widely spread along the line as it is harder to increase the total passenger number. The next graph shown in Figure 7.26. reveals another good comparison between actual and predicted values of the disposed number of passengers.

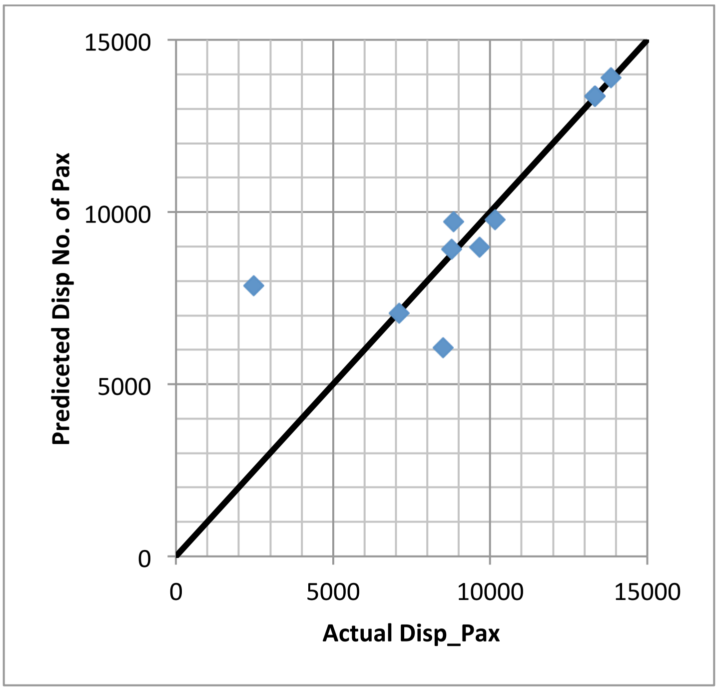


Figure 7.28 Obtained disposed passenger predicted from FIS across the actual value

The graph shows consistency and a high accuracy level of prediction as shown in Figure 7.28. , apart from the point (2488, 7871) as it is located far from the ideal prediction line. There is some fluctuation among the other predictions, yet they are still relatively good estimations.

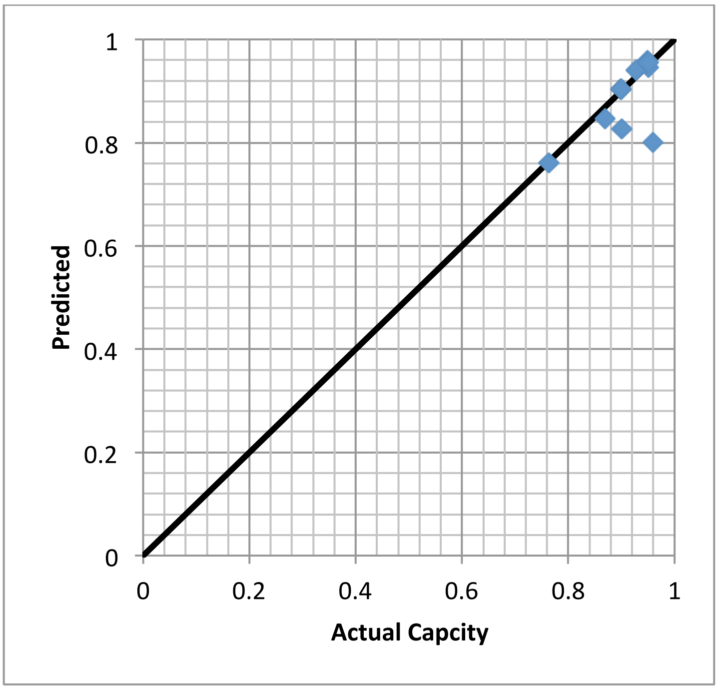


Figure 7.29 Obtained capacity predicted from FIS across the actual value

The last dependent variable is capacity, which varies in actual readings from 0 to 1. In airport terminals this variable should be as high as possible to achieve high utilisation and high performance and that is demonstrated in Figure 7.29 as it varies from 0.75 to 1. The least efficient prediction (0.960, 0.801) is still a good prediction of the actual capacity.

7.7 Summary

Analysis shows a great deal of improvement in predictions using fuzzy logic instead of linear regression for all dependent variables. PSO and GA optimisations are carried out and compared to the actual results gathered from the Arena simulation report. The cost function is the key to identifying which variable is important and to what extent it can be improved using normalisation. The main issue is that sometimes the optimiser leads toward some points that are an undefined area of the regression model, due to some limitations as it generates too many entities that cannot be handled by Arena. All results are compared to the actual readings and plotted in x-y charts which are revealed in this chapter for verification reasons.

Chapter 8 Conclusions and Future Work

8.1 Conclusions

This chapter illustrates the key conclusions of this research and reveals the future work potentials. The whole thesis has described research work carried out to achieve the assigned aims and objectives through the conceptual framework summarised in this chapter. The gaps still remaining, and future work required, are pointed out as a continuation of the development of the research. Limitations are also focused on, to assist with overcoming obstacles in any further study.

This study focuses on the integration of optimisation problem solving of the passenger process flow in airport terminals. It is expected that the **co**mputing techniques used, which accomplish practical optimisation problem solving instead of theoretical hypotheses which have yet to be verified, will help with planning and decision making in airport terminal operations.

In the proposed thesis, the literature review of Airport Level of service, Terminal and Modelling, Data Envelopment Analysis or (DEA) Modelling, Airport Simulation Modelling, Discrete Event Simulation (DES) and Optimisation, Performance, Airport Planning, and Airport Mathematical Analysis were revealed and used to build the bases of the offered optimisation system.

The thesis revealed the description of the essentials needed to carry out the research. That started with carrying out data collection either by survey, simulation model or from data sheets. Then the gathered figures were analysed by regression and correlation, handled by SPSS. LM was an alternative if a high error level was found, or ANFIS could be utilised. Arena was used to generate stochastic 'what if' scenarios that facilitated studying different operation situations and strategies that relate to an airport terminal authority. In addition, Arena had an input analyser which was found to be helpful in recognising resources' time functions. That all together allowed data to be fed to optimisers (GA or PSO) to show the decision making tool upon the cost function generated.

A global index for LOS assessments at airport terminals was produced. The key role of this assessment is naming the most significant attributes by considering user experience. This study was carried out in the Hajj terminal of the King Abdul-Aziz international airport, and classified processing time as being amongst the most important measures affecting the users' observations of the level of service. This motivated a DES (discreet event simulation) that focused on the processing time of each resource in the proposed simulation model. The gathered data related to time was also included. The outcomes of this study also point to the fact that some terminal attributes not examined in this study might have an input to the evaluation of LOS.

The simulation model building process started with using simulation steps in the designed route-station blocks and analysing gathered data from the airport terminal. An "Input analyser" is supportive software that has done the distribution expression recognising in that area. Considering that, the re-adjustment capability was considered to get the model prepared for the next required stage, applying sets or groups of trials (different 'what if' scenarios), as can be illustrated in the regression and fuzzy logic studies. Factors were captured at specific times to allow the production of a report to assist this research.

Results were gathered from executing the simulation model, initially with pax_t as a sample of influence on the output. Groups of diverse conditions and scenarios were conducted in Arena to get outputs that could be analysed for preparing a mathematical modelling of the system behaviour by varying the inputs of that simulation model. That can allow an optimisation study on the system which has been set as an aim of this research.

The analysis showed a great deal of improvement in prediction using fuzzy logic instead of linear regression for all dependent variables. PSO and GA optimisations were carried out and compared to the actual results gathered from the Arena simulation report. Cost function is the key to identifying which variable is important and to what extent it can be improved using normalisation. The main issue is that sometimes the optimiser leads toward some points that are in an undefined area of the regression model, due to some limitation as it generates too many entities that cannot be handled by Arena. All results are compared to the actual reading and plotted in x-y charts which were revealed for verification reasons.

8.2 Achievements

The overall aim of the thesis is to introduce an optimisation system as a novel paradigm in the computing environment with a customer perception element that can help as a performance indicator. The conceptual framework has the potential to bridge the gap between customers and the service provider.

The thesis also aims to offer a controllable simulation model that assesses an airport's performance. The thesis aims have been fulfilled through the following nine main contributions:

1. Review of literature and state of the art of measuring the terminal performance was conducted by looking at level of service assessment in the aviation field, and simulation methodologies which been used in prior studies.
2. Development of a survey questionnaire was done to allow LOS assessment of the airport terminal by using the global general index of passenger perception. Correlations were pointed out with regression in order to carry out a simulation model.
3. Data was collected from both ends: from passengers and from the airport operator via data sheets or from the conducted survey. These raw data have been selected and transformed into a form that can be analysed.
4. Data was analysed using the mathematical techniques of correlation, linear regression and LM algorithm, and the computer programming software of the Arena input analyser, MATLAB and SPSS.
5. A DES model was developed using Arena software which allows allocating of resources and generates time observations. This model was built to be used for generating trials which then allows the creation of a data driven model.
6. A data driven model was carried out by testing linear regression which showed a high level of error; then the LM algorithm showed a similar level of error; after that NF was used by ANFIS tools which have a high level of prediction accuracy.
7. A validation was made for each algorithm using the trials gathered from the Arena model execution. Graphical representation and analysis was carried out for every method and NF was elected to be a good data driven model.
8. Two optimisers were deployed; GA and PSO both showed a great deal of optimisation upon the cost function, though GA is preferred as it moves more randomly in the population.

9. The system was tested and showed a high level of accuracy, with room for improvement by trying different optimisation algorithms and generating more trials from the Arena model.
10. The system that can predict the airport capacity in order for its operational efficiency to be optimised is created by the integration of mentioned tools.

8.3 Limitations

Although this optimisation system model is holistic and capable of being applied to any airport, the implementation is prepared on one airport. There is an object maximum number limitation in the academic version of Arena which meant having some limitations on the trials' ranges to avoid any error during the model execution. Direct synchronisation between Excel and both the optimiser and the model or a direct link did not work properly as it could consume the PC memory and processor. Each trial took a long time respectively to get results which limited the number of trials that fed regression and NF. Optimisation still showed high time consumption in addition to the indefinite behaviour observed when it reached an unexplored point.

8.4 Future work

There are many additional ways of creating DES models and there are various diverse environments which could be studied as replications of this research, to allow for more alternatives and to allow greater performance optimisation to develop. Other data sheets from other airports and their passenger processes can be modelled and optimised using the proposed simulation model with some modification. The conceptual framework can be used in many fields other than aviation; transportation in general could easily benefit from the offered study. More links can be advised between survey output and simulation in any resource based processes. More optimisation techniques can be adopted and applied to the system. RFID might be a good integration to this system as it can develop the simulation model to be a real time simulation by a data acquisition system. There is still a gap of identify which is best for whom that means if a certain passenger journey is recorded, all associated performance measures along with their attributes should be attached in a structure as presented in MATLAB, or class as it is commonly used in C++ language. Future work can be beneficial to the optimisation system by feeding more data to and more output from the model, considering more airports in the study, deliberating more factors and exploring and using more data driven models (see figure 8.1).

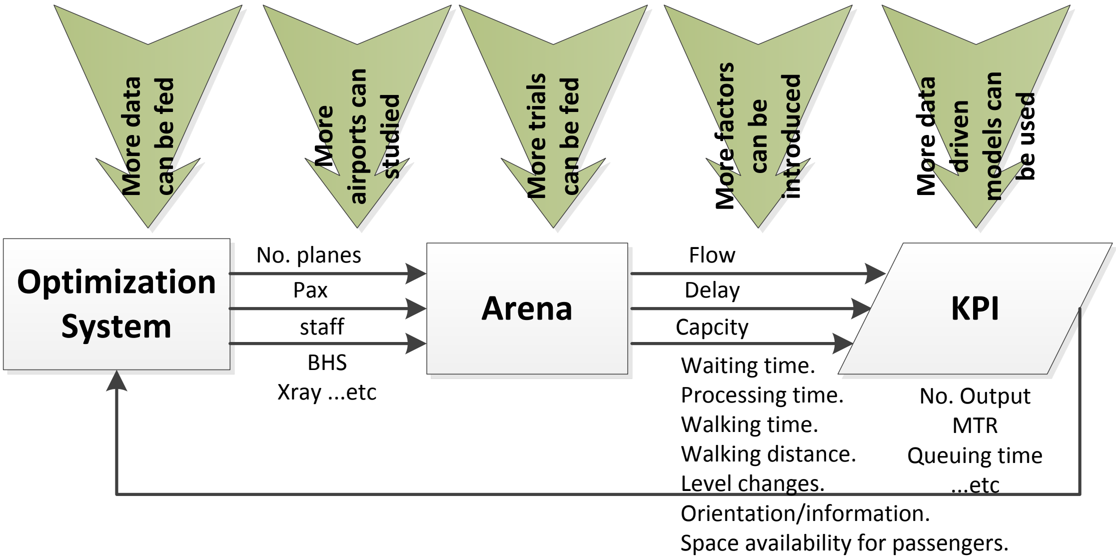


Figure 8.1 Gap and room of improvements

References

Aaker, D.A., Kumar, V., Day, G.S., 2003. Marketing Research, 8th ed. Wiley.

Abdelaziz, G.S., Hegazy, A.A., Elabbassy, A., 2010. Study of Airport Self-service Technology within Experimental Research of Check-in Techniques Case Study and Concept. International Journal of Computer Science Issues 7.

acme.highpoint.edu, n.d. Using SPSS for bivariate and multivariate regression [WWW Document]. URL http://acme.highpoint.edu/~msetzler/LCmethods/methmaterials/SPSSmultivariateRegression/using_spss_for_bivariate_and_mul.htm (accessed 8.1.14).

Adler, N., Berechman, J., 2001. Measuring airport quality from the airlines' viewpoint: an application of data envelopment analysis. Transport Policy 8, 171–181. doi:10.1016/S0967-070X(01)00011-7

aeroportsdeparis.fr, n.d. Accueil_international - Aéroports de Paris [WWW Document]. URL http://www.aeroportsdeparis.fr/ADP/en-GB/Group/Presentation/International/ (accessed 8.27.14).

Airports Council International, 2000. Quality of Service at Airports: Standards and Measurements. ACI World Headquarters, Geneva.

Air Transport Research Society, 2002. Airport Benchmarking Report, ATRS, Vancouver.

alglib.net, n.d. Levenberg-Marquardt algorithm for multivariate optimization. - ALGLIB [WWW Document]. URL http://www.alglib.net/optimization/levenbergmarquardt.php (accessed 3.4.14).

Al-Kanhal, T., 2010. An intelligent manufacturing system for heat treatment scheduling (Thesis). Brunel University School of Engineering and Design PhD Theses.

Al-Otaibi, M.M., Robinson, R.K., 2002. The dairy industry in Saudi Arabia: current situation and future prospects. Int J Dairy Tech 55, 75–78. doi:10.1046/j.1471-0307.2002.00048.x

Alrefaei, M.H., Andradóttir, S., 2001. A modification of the stochastic ruler method for discrete stochastic optimization. European Journal of Operational Research 133, 160–182. doi:10.1016/S0377-2217(00)00190-9

Altiok, T., Melamed, B., 2010. Simulation Modeling and Analysis with ARENA. Academic Press.

Andersson Granberg, T., Norin, A., Värbrand, P., Yuan, D., 2009. Integrating optimization and simulation to gain more efficient airport logistics, in: Eighth USA/Europe Air Traffic Management Research and Development Seminar (ATM2009). Eighth USA/Europe Air Traffic Management Research and Development Seminar (ATM2009).

Andradóttir, S., 1996. Optimization of the Transient and Steady-State Behavior of Discrete Event Systems. Management Science 42, 717–737. doi:10.2307/2634461

Andradóttir, S., 1998. A review of simulation optimization techniques, in: Simulation Conference Proceedings, 1998. Winter. Presented at the Simulation Conference Proceedings, 1998. Winter, pp. 151–158 vol.1. doi:10.1109/WSC.1998.744910

Andreatta, G., Brunetta, L., Odoni, A.R., Righi, L., Stamatopoulos, M.A., Zografos, K.G., 1999. A set of approximate and compatible models for airport strategic planning on airside and on landside. Air Traffic Control Quarterly 7, 291–317.

arenasimulation.com, n.d. Arena Simulation Software by Rockwell Automation: About Us [WWW Document]. URL http://www.arenasimulation.com/About_Us_About_Us.aspx (accessed 3.14.14).

Association, I.A.T., 2004. International Air Transport Association annual report'04. Switzerland: International Air Transport Association.

ats.ucla.edu, n.d. Regression with SPSS: Chapter 1 - Simple and Multiple Regression [WWW Document]. URL http://www.ats.ucla.edu/stat/spss/webbooks/reg/chapter1/spssreg1.htm (accessed 8.1.14).

aviationexplorer.com, 2007. heathrow_airport_terminal_4_arrivals.jpg (JPEG Image, 800 × 550 pixels) - Scaled (78%) [WWW Document]. URL http://www.aviationexplorer.com/LHR_london_heathrow_airport_terminal_maps/heathrow_airport_terminal_4_arrivals.jpg (accessed 1.22.15).

aviation-safety.net, 2013. Jeddah-King Abdulaziz International Airport profile - Aviation Safety Network [WWW Document]. URL http://aviation-safety.net/database/airport/airport.php?id=JED (accessed 8.25.14).

Avkiran, N.K., 2006. Productivity analysis in the service sector with data envelopment analysis. N.K. Avkiran, Ipswich, Qld.

Azad, A., Tokhi, O., 2007. AC 2007-727: MIGRATING FROM UNITED KINGDOM TO UNITED STATES AS A NEW FACULTY MEMBER.

Azadivar, F., 1999. Simulation optimization methodologies, in: Proceedings of the 31st Conference on Winter Simulation: Simulation---a Bridge to the Future-Volume 1. ACM, pp. 93–100.

Bandara, S., Wirasinghe, S.C., 1992. Walking distance minimization for airport terminal configurations. Transportation Research Part A: Policy and Practice 26, 59–74. doi:10.1016/0965-8564(92)90045-9

Banks, J., 2000. Introduction to simulation, in: Simulation Conference, 2000. Proceedings. Winter. Presented at the Simulation Conference, 2000. Proceedings. Winter, pp. 9–16 vol.1. doi:10.1109/WSC.2000.899690

Baron, P., 1969. A simulation analysis of airport terminal operations. Transportation Research 3, 481–491. doi:10.1016/0041-1647(69)90042-2

Bazargan, M., McGrath, R.N., 2003. Discrete event simulation to improve aircraft availability and maintainability, in: Reliability and Maintainability Symposium, 2003. Annual. IEEE, pp. 63–67.

Bazargan, M., Staschinski, S., Li, Y., 2008. Airbus-380 Aircraft boarding strategies: A simulation study AGIFORS Airlines Operations Study Group 2008 Montreal, AGIFORS Airlines. Montreal.

Beck, A., 2011. Case study: modelling passenger flows in Heathrow Terminal 5. J of Sim 5, 69–76. doi:10.1057/jos.2011.4

Biermann, F., 2001. Big science, small impacts--in the South? The influence of global environmental assessments on expert communities in India. Global Environmental Change 11, 297–309. doi:doi: DOI: 10.1016/S0959-3780(01)00008-5

Bishop, R.H., 2007. Mechatronic system control, logic, and data acquisition, 1st ed. CRC Press.

Brunetta, L., Righi, L., Andreatta, G., 1999. An operations research model for the evaluation of an airport terminal: SLAM (simple landside aggregate model). Journal of Air Transport Management 5, 161–175. doi:10.1016/S0969-6997(99)00010-1

Caldwell, N.D., Roehrich, J.K., Davies, A.C., 2009. Procuring complex performance in construction: London Heathrow Terminal 5 and a Private Finance Initiative hospital. Journal of Purchasing and Supply Management 15, 178–186. doi:10.1016/j.pursup.2009.05.006

Charnes, A., Cooper, W.W., Rhodes, E., 1978. Measuring the efficiency of decision making units. European Journal of Operational Research 2, 429–444.

Chaturvedi, D.K., 2010. Modeling and simulation of systems using MATLAB and Simulink. CRC Press, Boca Raton FL.

Chen, Y., Yang, B., Abraham, A., Peng, L., 2007. Automatic Design of Hierarchical Takagi ndash;Sugeno Type Fuzzy Systems Using Evolutionary Algorithms. IEEE Transactions on Fuzzy Systems 15, 385–397. doi:10.1109/TFUZZ.2006.882472

Chung, C.A., Nyakman, H., 1996. Operation of airport security checkpoints under increased threat conditions. Journal of transportation engineering 122, 264–269.

Clerc, M., Kennedy, J., 2002. The particle swarm - explosion, stability, and convergence in a multidimensional complex space. IEEE Transactions on Evolutionary Computation 6, 58–73. doi:10.1109/4235.985692

Confessore, G., Liotta, G., Grieco, R., 2005. A simulation-based architecture for supporting strategic and tactical decisions in the apron of Rome-Fiumicino airport, in: Simulation Conference, 2005 Proceedings of the Winter. Presented at the Simulation Conference, 2005 Proceedings of the Winter, p. 10 pp.–. doi:10.1109/WSC.2005.1574428

Cooper, W.W., Seiford, L.M., Tone, K., 2007. Data envelopment analysis: a comprehensive text with models, applications, references and DEA-solver software. Springer.

Correia, A.R., Wirasinghe, S.C., de Barros, A.G., 2005. A new procedure for overall level of service data collection at airport passenger terminals, in: Proceedings of the 9th ATRS World Conference, CD-ROM, Rio de Janeiro.

Correia, A.R., Wirasinghe, S.C., de Barros, A.G., 2008. Overall level of service measures for airport passenger terminals. Transportation Research Part A: Policy and Practice 42, 330–346. doi:10.1016/j.tra.2007.10.009

Correia, A.R., Wirasinghe, S.C., de Barros, A.G., 2008. A global index for level of service evaluation at airport passenger terminals. Transportation Research Part E: Logistics and Transportation Review 44, 607–620. doi:10.1016/j.tre.2007.05.009

Correia, A., Wirasinghe, S., 2004. Evaluating Level of Service at Airport Passenger Terminals: Review of Research Approaches. Transportation Research Record: Journal of the Transportation Research Board 1888, 1–6. doi:10.3141/1888-01

Coverley, P.T., Staszewski, W.J., 2003. Impact damage location in composite structures using optimized sensor triangulation procedure. Smart materials and structures 12, 795.

Cox, D.R., 1972. Regression Models and Life-Tables. Journal of the Royal Statistical Society. Series B (Methodological) 34, 187–220.

Crocker, J., Sheng, Q., 2008. Is prevention better than cure? Journal of Simulation 2, 53–60.

Dada, E.S., Wirasinghe, S.C., 1999. Development of a new orientation index for airport terminals. Transportation Research Record: Journal of the Transportation Research Board 1662, 41–47.

Dada, E., Wirasinghe, S., 2002. Estimating basic level of service for passenger orientation in new airports. Presented at the Proceedings of the 7th Conference of Hong Kong Society for Transportation Studies, Hong Kong, pp. 369–377.

Davies, A., Gann, D., Douglas, T., 2009. Innovation in megaprojects: Systems integration at London Heathrow terminal 5. California Management Review 51.

De Barros, A.G., Somasundaraswaran, A.K., Wirasinghe, S.C., 2007. Evaluation of level of service for transfer passengers at airports. Journal of Air Transport Management 13, 293–298. doi:10.1016/j.jairtraman.2007.04.004

De Barros, A.G., Wirasinghe, S.C., 2002. Design and shared use of a terminal departure lounge for new large aircraft operations. Journal of advanced transportation 36, 187–209.

De Barros, A.G., Wirasinghe, S.C., 2003. Optimal terminal configurations for new large aircraft operations. Transportation Research Part A: Policy and Practice 37, 315–331.

De Neufville, R., de Barros, A., Belin, S., 2002. Optimal Configuration of Airport Passenger Buildings for Travelers. Journal of Transportation Engineering 128, 211–217. doi:10.1061/(ASCE)0733-947X(2002)128:3(211)

Dorigo, M., Birattari, M., Stutzle, T., 2006. Ant colony optimization. IEEE Computational Intelligence Magazine 1, 28–39. doi:10.1109/MCI.2006.329691

Dyer, J.S., Fishburn, P.C., Steuer, R.E., Wallenius, J., Zionts, S., 1992. Multiple criteria decision making, multiattribute utility theory: the next ten years. Management science 38, 645–654.

Dyer, J.S., Sarin, R.K., 1979. Measurable multiattribute value functions. Operations Research 27, 810–822.

Eberhart, R.C., Kennedy, J., 1995. A new optimizer using particle swarm theory, in: Proceedings of the Sixth International Symposium on Micro Machine and Human Science. New York, NY, pp. 39–43.

Edwards, B., 2004. The Modern Airport Terminal: New Approaches to Airport Architecture. Taylor & Francis.

Elbeltagi, E., Hegazy, T., Grierson, D., 2005. Comparison among five evolutionary-based optimization algorithms. Advanced Engineering Informatics 19, 43–53. doi:10.1016/j.aei.2005.01.004

encyclopediaofmath.org, n.d. Correlation (in statistics) - Encyclopedia of Mathematics [WWW Document]. URL http://www.encyclopediaofmath.org/index.php/Correlation_(in_statistics) (accessed 2.3.14).

Engel, J.F., Blackwell, R.D., Miniard, P.W., 1995. Consumer behavior, eighth ed. ed. Dryden Press, Forth Worth, Tex.

Farrell, M.J., 1957. The Measurement of Productive Efficiency. Journal of the Royal Statistical Society. Series A (General) 120, 253. doi:10.2307/2343100

Fayez, M.S., Kaylani, A., Cope, D., Rychlik, N., Robinson, S., 2008. Managing airport operations using simulation. Journal of Simulation 2, 41–52. doi:10.1057/palgrave.jos.4250030

Fayez, M.S., Zavagnini, F., Mollaghasemi, M., 2011. Doing simulation for a living, in: Proceedings of the Winter Simulation Conference. Winter Simulation Conference, pp. 1481–1491.

Fernandes, E., Pacheco, R.R., 2002. Efficient use of airport capacity. Transportation Research Part A: Policy and Practice 36, 225–238. doi:10.1016/S0965-8564(00)00046-X

Field, A., 2009. Discovering Statistics Using SPSS, Third Edition. ed. Sage Publications Ltd.

Fishbein, M., Ajzen, I., 1975. Belief, attitude, intention, and behavior: an introduction to theory and research. Addison-Wesley Pub. Co., Reading, Mass.

flightstats.com, n.d. (GRU) Guarulhos International Airport [WWW Document]. URL http://www.flightstats.com/go/Airport/airportDetails.do?airportCode=GRU (accessed 12.28.11a).

flightstats.com, n.d. (JED) King Abdulaziz International Airport [WWW Document]. URL http://www.flightstats.com/go/Airport/airportDetails.do?airportCode=JED (accessed 12.28.11b).

Francis, G., Humphreys, I., Fry, J., 2002. The benchmarking of airport performance. Journal of Air Transport Management 8, 239–247. doi:10.1016/S0969-6997(02)00003-0

fraport.com, n.d. Fraport AG | Our Airports [WWW Document]. URL http://www.fraport.com/en/the-fraport-group/fraport-worldwide/our-airports.html (accessed 8.27.14).

gaca.gov.sa, n.d.

Galton, F., 1886. Regression Towards Mediocrity in Hereditary Stature. The Journal of the Anthropological Institute of Great Britain and Ireland 15, 246–263. doi:10.2307/2841583

Gatersleben, M.R., Van der Weij, S.W., 1999. Analysis and simulation of passenger flows in an airport terminal, in: Simulation Conference Proceedings, 1999 Winter. Presented at the Simulation Conference Proceedings, 1999 Winter, pp. 1226–1231 vol.2. doi:10.1109/WSC.1999.816845

Gavin, H., 2011. The Levenberg-Marquardt method for nonlinear least squares curve-fitting problems. Department of Civil and Environmental Engineering, Duke University.

gc.kls2.com, 2006. OEJN - Jeddah [King Abdulaziz Airport], SA - Airport - Great Circle Mapper [WWW Document]. URL http://gc.kls2.com/airport/OEJN (accessed 8.25.14).

Gillen, D., Lall, A., 1997. Developing measures of airport productivity and performance: An application of data envelopment analysis. Transportation Research Part E: Logistics and Transportation Review 33, 261–273.

Glynn, P.W., 1990. Likelihood ratio gradient estimation for stochastic systems. Commun. ACM 33, 75–84. doi:10.1145/84537.84552

Goldberg, D.E., 1989. Genetic Algorithms in Search, Optimization and Machine Learning, 1 edition. ed. Addison Wesley, Reading, Mass.

Golub, G.H., Van Loan, C.F., 1996. Matrix computations. Johns Hopkins University Press, Baltimore.

Gronfula, M., 2009. Assessing DES as a tool for analysing and improving passengers' process flow in airport terminal using Arena software. (MSc Dissertation). Brunel University, London, UK.

Grönroos, C., 1990. Service management and marketing: managing the moments of truth in service competition. Lexington Books Lexington, MA.

Gronroos, C., 1993. Quality comes to service. The Service Quality Handbook. AMACOM, New York, Scheduling, E.E., Christopher, W.F. (Eds.) 17–24.

Guizzi, G., Murino, T., Romano, E., 2009. A discrete event simulation to model passenger flow in the airport terminal, in: Proceedings of the 11th WSEAS International Conference on Mathematical Methods and Computational Techniques in Electrical Engineering (MMACTEE'09). pp. 427–434.

Hafizogullari, S., Chinnusamy, P., Tunasar, C., 2002. Transportation applications of simulation: simulation reduces airline misconnections: a case study, in: Proceedings of the 34th Conference on Winter Simulation: Exploring New Frontiers, WSC '02. Winter Simulation Conference, pp. 1192–1198.

Hahn, B.D., Valentine, D.T., 2013. Essential MATLAB for engineers and scientists.

Hart, W., 1985. The airport passenger terminal. Krieger Publishing Company.

heathrowairport.com, n.d. Heathrow: Airport management [WWW Document]. URL http://www.heathrowairport.com/about-us/company-news-and-information/company-information/airport-management (accessed 8.27.14).

Holland, J.H., 1973. Genetic Algorithms and the Optimal Allocation of Trials. SIAM Journal on Computing 2, 88–105. doi:10.1137/0202009

Holland, J.H., 1975. Adaptation in natural and artificial systems: An introductory analysis with applications to biology, control, and artificial intelligence. U Michigan Press, Oxford, England.

Hollocks, B.W., 1995. The impact of simulation in manufacturing decision making. Control Engineering Practice 3, 105–112. doi:10.1016/0967-0661(94)00070-W

Horonjeff, R., McKelvey, F., Sproule, W., Young, S., 2010. Planning and Design of Airports, Fifth Edition. Granite Hill Publishers.

Humphreys, I., Francis, G., 2000. Traditional Airport Performance Indicators: A Critical Perspective. Transportation Research Record: Journal of the Transportation Research Board 1703, 24–30. doi:10.3141/1703-04

Humphreys, I., Francis, G., 2002. Performance measurement: a review of airports. International Journal of Transport Management 1, 79–85. doi:10.1016/S1471-4051(02)00003-4

Hwang, C.L., Yoon, K., 1981. Multiple attribute decision making: methods and applications : a state-of-the-art survey. Springer-Verlag, Berlin; New York.

IBM.com, 2011. IBM Information Center masthead [WWW Document]. URL http://pic.dhe.ibm.com/infocenter/spssstat/v20r0m0/topic/com.ibm.ibmcom.doc/banner.htm (accessed 2.27.14).

ics.forth.gr, 2005. Levenberg-Marquardt in C/C++ [WWW Document]. URL http://users.ics.forth.gr/~lourakis/levmar/ (accessed 8.21.14).

Jacobs, P.H.M., Verbraeck, A., Mulder, J.B.P., 2005. Flight scheduling at KLM, in: Simulation Conference, 2005 Proceedings of the Winter. Presented at the Simulation Conference, 2005 Proceedings of the Winter, p. 8 pp.–. doi:10.1109/WSC.2005.1574264

Jang, J.-S.R., 1993. ANFIS: adaptive-network-based fuzzy inference system. IEEE Transactions on Systems, Man and Cybernetics 23, 665–685. doi:10.1109/21.256541

Jang, J.-S.R., Sun, C.-T., 1995. Neuro-fuzzy modeling and control. Proceedings of the IEEE 83, 378–406. doi:10.1109/5.364486

Jarach, D., 2001. The evolution of airport management practices: towards a multi-point, multi-service, marketing-driven firm. Journal of Air Transport Management 7, 119–125. doi:10.1016/S0969-6997(00)00038-7

jed-airport.com [WWW Document], n.d. URL http://www.jed-airport.com/about_existing.php (accessed 3.28.14).

Jim, H.K., Chang, Z.Y., 1998. An airport passenger terminal simulator: A planning and design tool. Simulation Practice and Theory 6, 387–396. doi:10.1016/S0928-4869(97)00018-9

Ju, Y., Wang, A., Che, H., 2007. Simulation and Optimization for the Airport Passenger Flow, in: International Conference on Wireless Communications, Networking and Mobile Computing, 2007. WiCom 2007. Presented at the International Conference on Wireless Communications, Networking and Mobile Computing, 2007. WiCom 2007, pp. 6605–6608. doi:10.1109/WICOM.2007.1621

Keeney, R.L., Raiffa, H, 1993. Decisions with multiple objectives: preferences and value trade-offs. Cambridge University Press.

Kelley, C.T., 1999. Iterative methods for optimization. Siam.

Kennedy, J., 2006. Swarm Intelligence, in: Zomaya, A.Y. (Ed.), Handbook of Nature-Inspired and Innovative Computing. Springer US, pp. 187–219.

Kennedy, J., Eberhart, R., 1995. Particle swarm optimization, in: Proceedings of 1995 IEEE International Conference on Neural Networks. pp. 1942–1948.

Kennedy, J.F., Eberhart, R.C., 2001. Swarm Intelligence. Morgan Kaufmann.

Kent, A., Williams, J.G., 1998. Encyclopedia of Computer Science and Technology: Volume 39 - Supplement 24 - Entity Identification to Virtual Reality in Driving Simulation.

CRC Press.

Kirschenbaum, A. (Avi), 2013. The cost of airport security: The passenger dilemma. Journal of Air Transport Management 30, 39–45. doi:10.1016/j.jairtraman.2013.05.002

Kobayashi, T., Simon, D.L., 2005. Hybrid neural-network genetic-algorithm technique for aircraft engine performance diagnostics. Journal of Propulsion and Power 21, 751–758.

Lampton, M., 1997. Damping–undamping strategies for the Levenberg–Marquardt nonlinear least-squares method. Computers in Physics 11, 110–115.

Lawson, C.L., Hanson, R.J., 1974. Solving least squares problems. SIAM.

Lemer, A.C., 1988. MEASURING AIRPORT LANDSIDE CAPACITY. Transportation Research Record.

Lemer, A.C., 1992. Measuring performance of airport passenger terminals. Transportation Research Part A: Policy and Practice 26, 37–45. doi:10.1016/0965-8564(92)90043-7

Levenberg, K., 1944. A method for the solution of certain problems in least squares. Quarterly of applied mathematics 2, 164–168.

Lewis-Beck, M.S., 1993. Regression analysis, (International handbooks of quantitative applications in the social sciences ; v. 2). Sage, London.

Lim, S.-R., Park, D., Park, J.M., 2008. Analysis of effects of an objective function on environmental and economic performance of a water network system using life cycle assessment and life cycle costing methods. Chemical Engineering Journal 144, 368–378. doi:10.1016/j.cej.2008.02.005

Liu, J.S., Lu, W.-M., 2010. DEA and ranking with the network-based approach: a case of R&D performance. Omega 38, 453–464. doi:10.1016/j.omega.2009.12.002

Liu, J.S., Lu, W.-M., Yang, C., Chuang, M., 2009. A network-based approach for increasing discrimination in data envelopment analysis. Journal of the Operational Research Society 60, 1502–1510.

Lourakis, M.I., 2005. A brief description of the Levenberg-Marquardt algorithm implemented by levmar. Foundation of Research and Technology 4, 1–6.

Madsen, K., Nielsen, H.B., Tingleff, O., 2004. Methods for non-linear least squares problems. Technical University of Denmark, 2004. Lecture notes [WWW Document]. URL http://www.imm.dtu.dk/courses/02611/nllsq.pdf.

Magri Jr, A.A., Alves, C.J.P., 2003. Convenient airports: point of view of the passengers, in: Air Transport Research Society World Conference.

Manataki, I.E., Zografos, K.G., 2009. A generic system dynamics based tool for airport terminal performance analysis. Transportation Research Part C: Emerging

Technologies 17, 428–443. doi:10.1016/j.trc.2009.02.001

Manataki, I.E., Zografos, K.G., 2010. Assessing airport terminal performance using a system dynamics model. Journal of Air Transport Management 16, 86–93. doi:10.1016/j.jairtraman.2009.10.007

Marquardt, D.W., 1963. An algorithm for least-squares estimation of nonlinear parameters. Journal of the Society for Industrial & Applied Mathematics 11, 431–441.

Martel, N., Seneviratne, P.N., 1990. Analysis of factors influencing quality of service in passenger terminal buildings. Transportation Research Record.

Mason, A.J., Ryan, D.M., Panton, D.M., 1998. Integrated Simulation, Heuristic and Optimisation Approaches to Staff Scheduling. Operations Research 46, 161–175. doi:10.1287/opre.46.2.161

mathworks.co.uk, n.d. MATLAB - The Language of Technical Computing - MathWorks United Kingdom [WWW Document]. URL http://www.mathworks.co.uk/products/matlab/ (accessed 2.27.14a).

mathworks.co.uk, n.d. Select solver and optimization options, run problems - MATLAB optimtool - MathWorks United Kingdom [WWW Document]. URL http://www.mathworks.co.uk/help/optim/ug/optimtool.html (accessed 8.1.14b).

mathworks.co.uk, n.d. Solve nonlinear curve-fitting (data-fitting) problems in least-squares sense - MATLAB lsqcurvefit - MathWorks United Kingdom [WWW Document]. URL http://www.mathworks.co.uk/help/optim/ug/lsqcurvefit.html (accessed 2.13.14c).

Mattila, M., Karjaluoto, H., Pento, T., 2003. Internet banking adoption among mature customers: early majority or laggards? Journal of Services Marketing 17, 514–528.

Miles, J., Shevlin, M., 2001. Applying regression and correlation: A guide for students and researchers. Sage.

Miller, R.G., 1997. Beyond ANOVA: Basics of Applied Statistics. CRC Press.

Mitchell, M., 1998. An introduction to genetic algorithms. MIT Press, Cambridge, Mass.

modelco.net, n.d. Modelco S.L., the model company >> Services - Case Study: WITNESS Helps Improve Operations at BAA [WWW Document]. URL http://modelco.net/en/ser_baa.php (accessed 8.25.14).

Müller, C., Gosling, G.D., 1991. A framework for evaluating level of service for airport terminals. Transportation Planning and Technology 16, 45–61. doi:10.1080/03081069108717470

Mumayiz, S.A., 1986. A methodology for planning and operations management of airport passenger terminals : a capacity/level of service approach (Ph.D.). Loughborough University.

Mumayiz, S.A., 1990. OVERVIEW OF AIRPORT TERMINAL SIMULATION MODELS. Transportation Research Record.

Mumayiz, S.A., 1991. Evaluating performance and service measures for the airport landside. Transportation Research Record.

Mumayiz, S., Ashford, N., 1986. Methodology for planning and operations management of airport terminal facilities.

National Instruments, 2011. What Is Data Acquisition? - National Instruments [WWW Document]. URL http://sine.ni.com/np/app/main/p/ap/daq/lang/en/pg/1/sn/n17:daq/fmid/652 (accessed 4.11.11).

Ndoh, N.N., Ashford, N.J., 1993. Evaluation of airport access level of service. Transportation Research Record.

Neofytou, P., Venetsanos, A.G., Vlachogiannis, D., Bartzis, J.G., Scaperdas, A., 2006. CFD simulations of the wind environment around an airport terminal building. Environmental Modelling & Software 21, 520–524. doi:10.1016/j.envsoft.2004.08.011

NeuroPie, n.d. Airport Performance Management [WWW Document]. URL http://www.neuropie.com/en/services/aviation-expertise/airport-performance-management.html (accessed 9.23.11).

Nielsen, H.B., 1999. Damping parameter in Marquardt's method. Informatics and Mathematical Modelling, Technical University of Denmark, DTU.

Norin, A., 2008. Airport Logistics : Modeling and Optimizing the Turn-Around Process.

Nwofia, O., Chung, C., 2013a. A Methodology for Designing Airports for Enhanced Security Using Simulation. Journal of Aviation Technology and Engineering 3. doi:10.7771/2159-6670.1066

Nwofia, O., Chung, C.A., 2013b. A Methodology for Designing Airports for Enhanced Security Using Simulation. Journal of Aviation Technology and Engineering 3, 1.

Odoni, A.R., 1991. Transportation modeling needs: airports and airspace. John A. Volpe National Transportation Center.

Odoni, A.R., de Neufville, R., 1992. Passenger terminal design. Transportation Research Part A: Policy and Practice 26, 27–35. doi:10.1016/0965-8564(92)90042-6

Ohira, M., Deguchi, H., Tsuji, M., Shigesawa, H., 2005. Novel waveguide filters with multiple attenuation poles using dual-behavior resonance of frequency-selective surfaces. Microwave Theory and Techniques, IEEE Transactions on 53, 3320–3326.

Olaru, D., Emery, S.J., 2007. Simulation and GA-optimization for modeling the operation of airport passenger terminals. Presented at the Conference of Australian Institutes of

Transport Research (CAITR).

Omer, K.F., Khan, A.M., 1988. Airport landside level of service estimation: utility theoretic approach.

Otamendi, J., Pastor, J.M., Garcı´a, A., 2008. Selection of the simulation software for the management of the operations at an international airport. Simulation Modelling Practice and Theory 16, 1103–1112. doi:10.1016/j.simpat.2008.04.022

Oum, T.H., Yu, C., Fu, X., 2003. A comparative analysis of productivity performance of the world's major airports: summary report of the ATRS global airport benchmarking research report—2002. Journal of Air Transport Management 9, 285–297. doi:10.1016/S0969-6997(03)00037-1

Parasuraman, A., Zeithaml, V.A., Berry, L.L., 1985. A conceptual model of service quality and its implications for future research. The Journal of Marketing 41–50.

Parasuraman, A., Zeithaml, V.A., Berry, L.L., 1988. SERVQUAL: a multiple-item scale for measuring consumer perception of service quality. Journal of retailing 64, 12–40.

Pardee, F.S., Kirkwood, T.F., MacCrimmon, K.R., Miller, J.R., Phillips, C.T., Ranftl, J.W., Smith, K.V., Whitcomb, D.K., 1969. Measurement and evaluation of transportation system effectiveness.

Park, Y.H., 1994. An evaluation methodology for the level of service at the airport landside system. © YH Park.

Pearl, J., 1984. Heuristics: Intelligent Search Strategies for Computer Problem Solving. Addison-Wesley.

performance airport simulation arena optimization - Google Scholar [WWW Document], n.d. URL http://scholar.google.co.uk/scholar?hl=en&q=performance+airport+simulation+arena+optimization&btnG=&as_sdt=1%2C5&as_sdtp= (accessed 3.26.13).

ppmdc.com.sa, 2014. PPMDC - The Port Specialist - Home [WWW Document]. URL http://ppmdc.com.sa/index.php (accessed 8.27.14).

Press, W.H., Teukolsky, S.A., Vetterling, W.T., Flannery, B.P., n.d. Numerical recipes in C, 1992. Cambridge: Cambridge University.

Rauch, R., Kljajić, M., 2006. Discrete Event Passenger Flow Simulation Model for an Airport Terminal Capacity Analysis. Organizacija 39.

Rezaie, B., Esmailzadeh, E., Dincer, I., 2011. Renewable energy options for buildings: Case studies. Energy and Buildings 43, 56–65. doi:10.1016/j.enbuild.2010.08.013

Robinson, S., 2004. Simulation the practice of model development and use. Wiley, Chichester, Eng.; Hoboken, N.J.

Robinson, S., 2005. Discrete-Event Simulation: From the Pioneers to the Present, What Next? The Journal of the Operational Research Society 56, 619–629. doi:10.2307/4102035

Rubinstein, R.Y., Shapiro, A., 1993. Discrete event systems: sensitivity analysis and stochastic optimization by the score function method. Wiley.

Saravanan, R., 2006. Manufacturing Optimization through Intelligent Techniques. CRC Press.

Seitzinger, S.P., Kroeze, C., Styles, R.V., 2000. Global distribution of N2O emissions from aquatic systems: natural emissions and anthropogenic effects. Chemosphere - Global Change Science 2, 267–279. doi:doi: DOI: 10.1016/S1465-9972(00)00015-5

Seneviratne, P.N., Martel, N., 1991a. Variables influencing performance of air terminal buildings. Transportation Planning and Technology 16, 3–28. doi:10.1080/03081069108717468

Seneviratne, P.N., Martel, N., 1991b. Variables influencing performance of air terminal buildings. Transportation Planning and Technology 16, 3–28.

Shannon, R.E., 1998. Introduction to the Art and Science of Simulation, in: Proceedings of the 30th Conference on Winter Simulation, WSC ’98. IEEE Computer Society Press, Los Alamitos, CA, USA, pp. 7–14.

Sharma, A.K., 2008. Equilibrium modeling of global reduction reactions for a downdraft (biomass) gasifier. Energy Conversion and Management 49, 832–842. doi:10.1016/j.enconman.2007.06.025

Sharma, N.K., 2008. Predicting and Reducing Warranty Costs by Considering Customer Expectation and Product Performance. ProQuest.

Sheskin, D.J., 2003. Handbook of Parametric and Nonparametric Statistical Procedures: Third Edition. CRC Press.

Siddiqui, M.R., 1994. A statistical analysis of the factors influencing the level of service of airport terminal curbsides. Concordia University.

siemens.com, 2011. Siemens Global Website [WWW Document]. URL http://www.mobility.siemens.com/mobility/global/SiteCollectionDocuments/en/integrated-mobility/future-of-hubs/hubs-of-the-future-en.pdf (accessed 8.27.14).

Smith, J.S., 2002. Evolving a better solution. Developers Network Journal.

Snowdon, J.L., MacNair, E., Montevecchi, M., Callery, C.A., El-Taji, S., Miller, S., 2000. IBM Journey Management Library: An Arena System for Airport Simulations. The Journal of the Operational Research Society 51, 449–456. doi:10.2307/254172

statistics.com, n.d. Statistics.com - Glossary of statistical terms [WWW Document]. URL http://www.statistics.com/glossary&term_id=246 (accessed 8.1.14a).

statistics.com, n.d. Statistics.com - Glossary of statistical terms [WWW Document]. URL http://www.statistics.com/glossary&term_id=242 (accessed 8.1.14b).

statistics.laerd.com, n.d. How to perform a Multiple Regression Analysis in SPSS | Laerd Statistics [WWW Document]. URL https://statistics.laerd.com/spss-tutorials/multiple-regression-using-spss-statistics.php (accessed 8.1.14a).

statistics.laerd.com, n.d. Linear Regression Analysis in SPSS - Procedure, assumptions and reporting the output. [WWW Document]. URL https://statistics.laerd.com/spss-tutorials/linear-regression-using-spss-statistics.php (accessed 8.1.14b).

statistics.laerd.com, n.d. Pearson's Product-Moment Correlation in SPSS - Procedure, assumptions, and output using a relevant example. [WWW Document]. URL https://statistics.laerd.com/spss-tutorials/pearsons-product-moment-correlation-using-spss-statistics.php (accessed 2.27.14c).

statistics.laerd.com, n.d. Spearman's Rank Order Correlation using SPSS - A How-To Statistical Guide by Laerd Statistics [WWW Document]. URL https://statistics.laerd.com/spss-tutorials/spearmans-rank-order-correlation-using-spss-statistics.php (accessed 2.27.14d).

Stewart, T.J., 1992. A critical survey on the status of multiple criteria decision making theory and practice. Omega 20, 569–586.

strath.ac.uk, n.d. Linear Regression Analysis on SPSS - University of Strathclyde [WWW Document]. URL http://www.strath.ac.uk/aer/materials/4dataanalysisineducationalresearch/unit4/linearregressionanalysisonspss/ (accessed 8.1.14).

Swisher, J.R., Hyden, P.D., Jacobson, S.H., Schruben, L.W., 2004. A survey of recent advances in discrete input parameter discrete-event simulation optimization. IIE Transactions 36, 591–600. doi:10.1080/07408170490438726

Swisher, J.R., Jacobson, S.H., Yücesan, E., 2003. Discrete-event simulation optimization using ranking, selection, and multiple comparison procedures: A survey. ACM Trans. Model. Comput. Simul. 13, 134–154. doi:10.1145/858481.858484

Taha, H.A., 2010. Operations Research: An Introduction, 9 edition. ed. Prentice Hall, Upper Saddle River, N.J.

Takagi, T., Sugeno, M., 1985. Fuzzy identification of systems and its applications to modeling and control. IEEE Transactions on Systems, Man and Cybernetics SMC-15, 116–132. doi:10.1109/TSMC.1985.6313399

Takakuwa, S., Oyama, T., 2003. Modeling people flow: simulation analysis of international-departure passenger flows in an airport terminal, in: Proceedings of the 35th Conference on Winter Simulation: Driving Innovation, WSC '03. Winter Simulation Conference, New Orleans, Louisiana, pp. 1627–1634.

Taylor, B.W., 2012. Introduction to Management Science, 11 edition. ed. Prentice Hall, Boston.

Tošić, V., 1992. A review of airport passenger terminal operations analysis and modelling. Transportation Research Part A: Policy and Practice 26, 3–26. doi:10.1016/0965-8564(92)90041-5

Transportation Research Board (TRB), 1987. Special Report 215: Measuring Airport Landside Capacity. TRB, National Research Council, Washington, DC.

Transportation Research Board (TRB), 2000a. Airport–airspace simulations for capacity evaluation. Transportation Research E-Circular Number E-C035. 79th TRB Annual Meeting. In. Proceedings of the Workshop Organized by the TRB Committee on Airfield and Airspace Capacity and Delay (A1J05), Washington, DC.

Transportation Research Board (TRB), 2000b. Highway Capacity Manual. Special Report # 209, TRB, National Research Council, Washington, DC.

Valentin, E., 2002. Building blocks for modeling of passengers at airports. Building blocks for Effective Telematics Application Development and Evaluation 148.

Van Huffel, S., Vandewalle, J., 1991. The total least squares problem: computational aspects and analysis. Siam.

Van Landeghem, H., Beuselinck, A., 2002. Reducing passenger boarding time in airplanes: A simulation based approach. European Journal of Operational Research 142, 294–308. doi:10.1016/S0377-2217(01)00294-6

Verbraeck, A., Valentin, E., 2002. Transportation applications of simulation: simulation building blocks for airport terminal modeling, in: Proceedings of the 34th Conference on Winter Simulation: Exploring New Frontiers, WSC '02. Winter Simulation Conference, San Diego, California, pp. 1199–1206.

Weisberg, S., 2005. Applied linear regression. Wiley-Interscience, Hoboken, NJ.

Weisstein, E.W., n.d. Levenberg-Marquardt Method -- from Wolfram MathWorld [WWW Document]. URL http://mathworld.wolfram.com/Levenberg-MarquardtMethod.html (accessed 3.4.14).

Wirasinghe, S.C., Bandara, S., 1990. Airport gate position estimation for minimum total costs—Approximate closed form solution. Transportation Research Part B: Methodological 24, 287–297. doi:10.1016/0191-2615(90)90003-H

Wirasinghe, S.C., Shehata, M., 1989. Departure lounge sizing and optimal seating capacity for a given aircraft/flight mix — (i) single gate. (ii) several gates. Transportation Planning and Technology 13, 57–71. doi:10.1080/03081068808717388

Woodall, T., 2001. Six Sigma and Service Quality: Christian Grönroos Revisited. Journal of Marketing Management 17, 595–607. doi:10.1362/026725701323366953

worldaerodata.com, n.d. World Aero Data: KING ABDULAZIZ INTL -- OEJN [WWW

Document]. URL http://worldaerodata.com/wad.cgi?id=SA02739&sch=OEJN (accessed 8.25.14).

Wright, S.J., Nocedal, J., 1999. Numerical optimization. Springer New York.

Wu, P.P.-Y., Mengersen, K., 2013. A review of models and model usage scenarios for an airport complex system. Transportation Research Part A: Policy and Practice 47, 124–140. doi:10.1016/j.tra.2012.10.015

www.airbus.com, 2014. A380 - A380 photos, pictures, A380 videos, A380 3D view | Airbus | Airbus, a leading aircraft manufacturer [WWW Document]. URL http://www.airbus.com/aircraftfamilies/passengeraircraft/a380family/ (accessed 5.15.14).

WYLAND, B., BUXTON, K., FUQUA, B., 2000. Simulating the supply chain. IIE SOLUTIONS 37–42.

Xie, Y., Shortle, J., Donohue, G., 2004. Airport terminal-approach safety and capacity analysis using an agent-based model, in: Simulation Conference, 2004. Proceedings of the 2004 Winter. Presented at the Simulation Conference, 2004. Proceedings of the 2004 Winter, pp. 1349–1357 vol.2. doi:10.1109/WSC.2004.1371471

Xu, C.-W., Lu, Y.-Z., 1987. Fuzzy Model Identification and Self-Learning for Dynamic Systems. IEEE Transactions on Systems, Man and Cybernetics 17, 683–689. doi:10.1109/TSMC.1987.289361

Xu, T., Zuo, W., Xu, T., Song, G., Li, R., 2010. An adaptive reanalysis method for genetic algorithm with application to fast truss optimization. Acta Mechanica Sinica 26, 225–234.

Yamin, M., 2008. A Framework for Improved Hajj Management and Future Research. ENTIC Bull 2, 08.

Yan, X., 2009. Linear Regression Analysis: Theory and Computing. World Scientific.

Yeh, C.H., Deng, H., Pan, H., 1999. Multi-criteria analysis for dredger dispatching under uncertainty. Journal of the Operational Research Society 35–43.

Yeh, C.-H., Kuo, Y.-L., 2003. Evaluating passenger services of Asia-Pacific international airports. Transportation Research Part E: Logistics and Transportation Review 39, 35–48. doi:10.1016/S1366-5545(02)00017-0

Yen, J.R., 1995. A new approach to measure the level of service of procedures in the airport landside. Transportation Planning Journal 24, 323–336.

Yen, J.-R., Teng, C.-H., Chen, P.S., 2001. Measuring the level of services at airport passenger terminals: Comparison of perceived and observed time. Transportation Research Record: Journal of the Transportation Research Board 1744, 17–33.

Ying, H., 2000. Theory and application of a novel fuzzy PID controller using a simplified

Takagi–Sugeno rule scheme. Information Sciences 123, 281–293. doi:10.1016/S0020-0255(99)00133-4

Young, S.B., Wells, A.T., 2011. Airport planning and management. McGraw-Hill ; [McGraw-Hill [distributor], New York; London.

Yu, M.-M., 2004. Measuring physical efficiency of domestic airports in Taiwan with undesirable outputs and environmental factors. Journal of Air Transport Management 10, 295–303. doi:10.1016/j.jairtraman.2004.04.001

Yu, M.-M., 2010. Assessment of airport performance using the SBM-NDEA model. Omega 38, 440–452. doi:10.1016/j.omega.2009.11.003

Zhu, J., 2009. Quantitative models for performance evaluation and benchmarking: data envelopment analysis with spreadsheets. Springer, New York, NY.

Appendix A - Questionnaire

Dear Participant,

This short survey designed to collect your constructive feedback about the airport terminal process flow or your journey from the gate of the plane to the end of the x-ray customs check. Based on recent journey in the terminal please answer the following questions:

1. Did you come from the plane through a bus or jet way directly to the terminal?
□ Bus □ Jet way

Please specify the waiting time for each of the following process:
2. Walking time between the terminal entrances to the immigration counter?
- □ 5min or less
- □ 10min or less
- □ 15min or less
- □ 20min or less
- □ More

3. Waiting in vaccination?
- □ 15min or less
- □ 30min or less
- □ 60min or less
- □ 120min or less
- □ More

4. Waiting in passport check?
- □ 15min or less
- □ 30min or less
- □ 60min or less
- □ 120min or less
- □ More

5. Waiting in Baggage claim (collection of your baggage)?
□ 15min or less □ 30min or less □ 60min or less □ 120min or less □ More

6. Waiting in on X-ray?
□ 15min or less □ 30min or less □ 60min or less □ 120min or less □ More

7. Total waiting time on the airport before coming to plaza or waiting area?
□ 15min or less □ 30min or less □ 60min or less □ 120min or less □ More

How do you rate the following?
8. Processing time in the airport terminal?
Total time required for immigration processing, customs inspection, and luggage claiming.
□ 1-unacceptable □ 2-poor □ 3-regular □ 4-good □ 5-excellent

9. Delay in the airport terminal?
Service times: check-in, baggage claim, waiting times, variability of wait, etc.
□ 1-unacceptable □ 2-poor □ 3-regular □ 4-good □ 5-excellent

10. Comfort Cleanliness in the airport terminal?
That concerns lighting and congestion level of waiting areas/lounges, and ambience of the airport as a whole.
□ 1-unacceptable □ 2-poor □ 3-regular □ 4-good □ 5-excellent

11. Courtesy of staff in the airport terminal?
Helpfulness, friendliness and courtesy of airport staff.
Availability of assistance for disabled.
□ 1-unacceptable □ 2-poor □ 3-regular □ 4-good □ 5-excellent

12. Convenience in the airport terminal?
Availability/accessibility of trolleys, washrooms, shops, restaurants, money exchange, cash Machines, luggage carts, and rental facilities trolleys.
□ 1-unacceptable □ 2-poor □ 3-regular □ 4-good □ 5-excellent

13. Information visibility?
Clearness and/or frequency of information display for flights, airport facilities and signposting. Flight information display system (FIDS).
□ 1-unacceptable □ 2-poor □ 3-regular □ 4-good □ 5-excellent

14. Security?
Sense of security about airport safety measures and security facilities.
□ 1-unacceptable □ 2-poor □ 3-regular □ 4-good □ 5-excellent

15. Service?
Service "justice" (first in, first out), spatial logic, signing or sightlines reasonableness.
□ 1-unacceptable □ 2-poor □ 3-regular □ 4-good □ 5-excellent

Your gender is
□ Male □ Female
Your age is..................
Thank you very much for your time

Appendix B - PPMDC data sheets

PPMDC The ports specialist شركة ادارة وتطوير مشاريع الموانئ المحدودة Ports Projects Management and Development Co. Ltd.	HAJJ SEASON 1434H - 2013G **Commercial Departure-Statistical Section** ALL TERMINAL DAILY STATISTICAL REPORT (DSR4)	DIN	PPMDC-STT-T-01
		RN	0
		ED	10/02/2013

ARRIVAL MODE

Mon **14-Oct-13** **09/12/1434**

DATE	SKD FLTS	HAJJ TERML								NT,ST & ARBSCO TERML		SUB TTL ALL TRMLS	
		HAJJ FLTS		NORMAL SKD		NORMAL		TTL					
		FLT	PAX	FLT	PAX	FLT	PAX	FLT	PAX	FLT	PAX	FLT	PAX
07-Sep-13	4	4	1,209	2	120	14	1,195	20	2,524	0	0	20	2,524
08-Sep-13	8	7	1,927	23	2,171	2	367	32	4,465	0	0	32	4,465
09-Sep-13	16	17	5,173	29	2,943	3	442	49	8,558	0	0	49	8,558
10-Sep-13	25	24	8,594	28	2,340	4	523	56	11,457	0	0	56	11,457
11-Sep-13	28	26	9,257	26	3,579	2	167	54	13,003	0	0	54	13,003
12-Sep-13	22	23	8,419	23	2,435	5	1,162	51	12,016	0	0	51	12,016
13-Sep-13	28	24	9,106	26	3,408	4	947	54	13,461	0	0	54	13,461
14-Sep-13	25	22	7,983	25	2,522	6	1,160	53	11,665	0	0	53	11,665
15-Sep-13	27	24	9,001	28	1,990	3	860	55	11,851	0	0	55	11,851
16-Sep-13	35	30	11,542	29	2,415	4	627	63	14,584	0	0	63	14,584
17-Sep-13	32	25	9,184	33	2,629	4	1,210	62	13,023	0	0	62	13,023
18-Sep-13	28	26	9,392	24	2,316	3	563	53	12,271	0	0	53	12,271
19-Sep-13	33	30	10,526	33	2,527	4	825	67	13,878	0	0	67	13,878
20-Sep-13	32	29	9,345	33	2,419	5	636	67	12,400	0	0	67	12,400
21-Sep-13	35	32	10,918	33	2,645	3	631	68	14,194	0	0	68	14,194
22-Sep-13	37	35	11,371	38	2,430	2	357	75	14,158	0	0	75	14,158
23-Sep-13	44	38	12,291	33	2,104	5	1,158	76	15,553	0	0	76	15,553
24-Sep-13	47	38	11,708	44	3,310	8	1,980	90	16,998	0	0	90	16,998
25-Sep-13	58	52	17,437	58	4,728	7	377	117	22,542	0	0	117	22,542
26-Sep-13	65	64	22,002	61	5,367	10	1,347	135	28,716	0	0	135	28,716
27-Sep-13	81	76	25,444	64	6,456	11	908	151	32,808	0	0	151	32,808
28-Sep-13	75	67	22,634	59	5,786	8	951	134	29,371	0	0	134	29,371
29-Sep-13	76	73	24,501	63	5,425	6	596	142	30,522	0	0	142	30,522
30-Sep-13	79	73	24,813	72	7,804	11	1,325	156	33,942	0	0	156	33,942
01-Oct-13	88	83	25,986	88	11,513	8	1,519	179	39,018	0	0	179	39,018
02-Oct-13	85	84	26,164	94	12,071	13	1,473	191	39,708	0	0	191	39,708
03-Oct-13	89	86	26,764	83	9,944	15	2,040	184	38,748	0	0	184	38,748
04-Oct-13	93	90	28,693	89	11,187	17	2,035	196	41,915	0	0	196	41,915
05-Oct-13	105	98	30,656	95	13,095	10	1,175	203	44,926	0	0	203	44,926
06-Oct-13	98	89	28,569	90	12,769	16	2,285	195	43,623	0	0	195	43,623
07-Oct-13	94	92	28,703	100	15,025	21	3,586	213	47,314	0	0	213	47,314
08-Oct-13	107	100	29,763	98	16,000	21	3,194	219	48,957	0	0	219	48,957
09-Oct-13	124	116	35,005	109	20,904	24	4,233	249	60,142	0	0	249	60,142
10-Oct-13	6	11	4,201	40	2,854	26	4,262	77	11,317	0	0	77	11,317
11-Oct-13	1	2	917	30	789	8	367	40	2,073	0	0	40	2,073
12-Oct-13	0	0	0	35	515	1	2	36	517	0	0	36	517
13-Oct-13	0	0	0	21	208	5	61	26	269	0	0	26	269
14-Oct-13	0	0	0	5	56	0	0	5	56	0	0	5	56
TOTAL	**1,830**	**1,710**	**559,198**	**1,864**	**206,799**	**319**	**46,546**	**3,893**	**812,543**	**0**	**0**	**3,893**	**812,543**

DATE	HAJJ TERML Domestic FLTS	
	FLT	PAX
07-Sep-13	0	0
08-Sep-13	0	0
09-Sep-13	0	0
10-Sep-13	0	0
11-Sep-13	0	0
12-Sep-13	0	0
13-Sep-13	0	0
14-Sep-13	0	0
15-Sep-13	0	0
16-Sep-13	0	0
17-Sep-13	0	0
18-Sep-13	2	71
19-Sep-13	1	18
20-Sep-13	1	3
21-Sep-13	3	7
22-Sep-13	7	122
23-Sep-13	7	238
24-Sep-13	4	66
25-Sep-13	4	57
26-Sep-13	3	57
27-Sep-13	5	107
28-Sep-13	7	90
29-Sep-13	8	132
30-Sep-13	8	95
01-Oct-13	8	267
02-Oct-13	9	314
03-Oct-13	10	489
04-Oct-13	9	603
05-Oct-13	9	594
06-Oct-13	13	1,373
07-Oct-13	9	711
08-Oct-13	2	124
09-Oct-13	0	0
10-Oct-13	0	0
11-Oct-13	0	0
12-Oct-13	0	0
13-Oct-13	0	0
14-Oct-13	0	0
TOTAL	**129**	**5,538**

TODAY SCHEDULE FLIGHTS

15-Oct-13

ARR	0
DEP	0
TTL	0

HAJJ TERML ACTL OPRTD FLTS

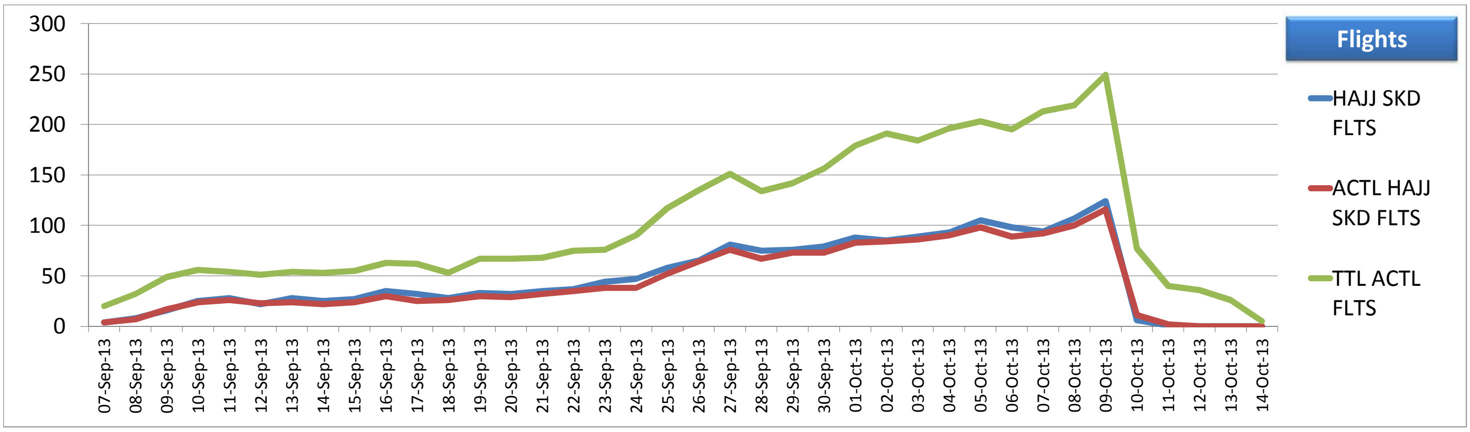
SKD	0	0.00%
NON SKD	0	0.00%
Normal	0	0.00%
Normal SKD	5	100.00%
TTL	5	100.00%

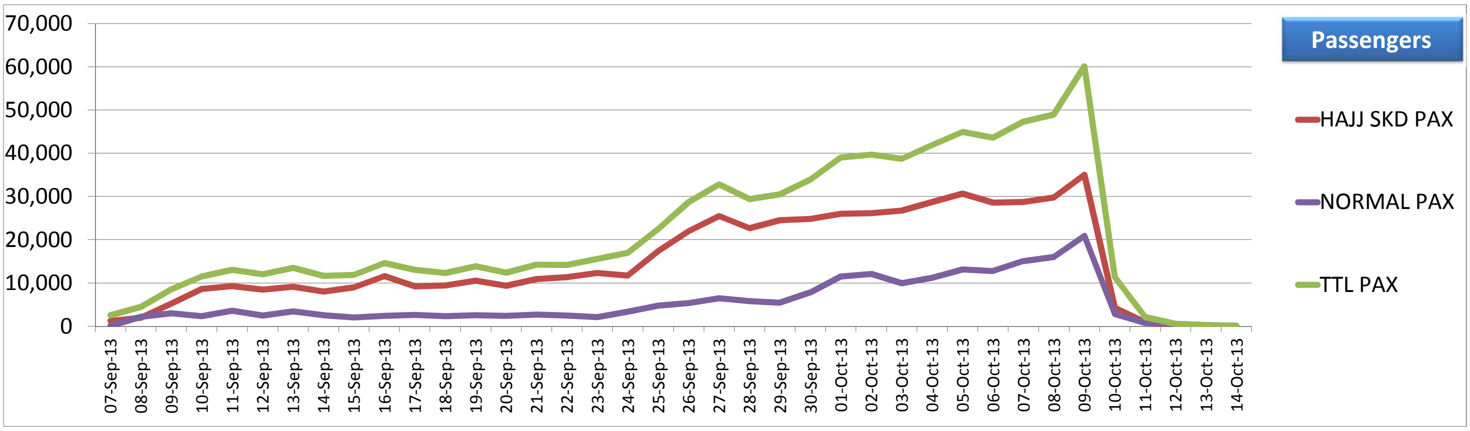
Hassan M. Khalawi
Commercial Manager

Prepared by : Statistical Section   Printed on: 30/08/2014 18:11   Programmed by: Abdullah Alqarni

ARRIVAL MODE

Mon 14-Oct-13 09/12/1434





Hajj Terminal – King Abdul-Aziz International Airport

Hajj & Ummrah Terminal

Weekly Analyzing performance Report

May , 2011

Period from Saturday 07/05/2011 Up To Thursday 12/05/2011

Arrival & Departure

TABLE OF CONTENTS

TABLE OF CONTENTS

SUMMARY

This report is issued in order to fulfill the requirements stated in the MTR Guidelines.

This report gives an overall view, breakdown and analysis of operational activities user of HTC complex in the terminal used. It includes statistical information and analyzing regarding passengers and flight traffic.

The timeframe covered herein dates from:

07th to 12th May 2011

Corresponding to

04th to 09th Jamad Al-Akher 1432H

Immigration Arrival (Statistic)

Saturday 07/05/2011

(Statistic Per passenger)

#	Flight #	Counters #	sex	Actual Time For Queuing Until Counters		MTR	Actual Processing Time At The Counters		MTR	Total staff	Remarks
				Start	Complete		Start	Complete			
1	SV 2887	2	M	02:50	03:23	30 minute	03:25	03:31	118 Sec	3	-----------
Total Time				33 Min			6 Min				
2	IR 2649	2	F	03:40	04:15	30 minute	04:18	04:22	118 Sec	4	-----------
Total Time				35 Min			4 Min				
3	W5 5094	2	F	12:08	12:44	30 minute	12:46	12:50	118 Sec	5	-----------
Total Time				36 Min			4 Min				

(Statistic Per Flight)

#	Flight #	Counters #	Total PAX	Actual Time For Queuing Until Counter		MTR	Actual Processing Time At The Counter		MTR	Total staff	Remarks
				Start	Complete		Start	Complete			
1	SV 2887	2	294	02:15	03:40	Max 30 min. per passenger	02:17	03:45	Max 118 sec. per passenger	3	-----------
Total Time				01:25 Hrs.			01:27 Hrs.				
Average Time Per Passenger				17 Sec.			17 Sec.				
Total Time For All Flight				01:30 Hrs.							
2	IR 2649	2	429	03:40	04:40	Max 30 min. per passenger	03:50	04:42	Max 118 sec. per passenger	4	-----------
Total Time				01:00 Hrs.			52 Min.				
Average Time Per Passenger				8 Sec.			8 Sec.				
Total Time For All Flight				01:02 Hrs.							
3	W5 5094	2	441	12:08	13:28	Max 30 min. per passenger	12:14	13:31	Max 118 sec. per passenger	5	-----------
Total Time				01:20 Hrs.			01:07 Hrs.				
Average Time Per Passenger				8 Sec.			8 Sec.				
Total Time For All Flight				01:23 Hrs.							

Immigration Arrival (Statistic)

Sunday 08/05/2011

(Statistic Per passenger)

#	Flight #	Counters #	sex	Actual Time For Queuing Until Counters		MTR	Actual Processing Time At The Counters		MTR	Total staff	Remarks
				Start	Complete		Start	Complete			
1	IR 2667	2	M	10:31	10:52	30 minute	10:52	10:55	118 Sec	5	-----------
Total Time				33 Min			6 Min				
2	MS 661	2	F	10:55	11:09	30 minute	11:10	11:15	118 Sec	4	-----------
Total Time				35 Min			4 Min				
3	IA 5069	2	M	11:11	11:44	30 minute	11:13	11:15	118 Sec	4	-----------
Total Time				36 Min			4 Min				

(Statistic Per Flight)

#	Flight #	Counters #	Total PAX	Actual Time For Queuing Until Counter		MTR	Actual Processing Time At The Counter		MTR	Total staff	Remarks
				Start	Complete		Start	Complete			
1	9P 2101	2	72	10:40	10:55	Max 30 min. per passenger	10:43	12:03	Max 118 sec. per passenger	5	-----------
Total Time				15 Min.			20 Min.				
Average Time Per Passenger				12 Sec			13 Sec				
Total Time For All Flight				01:13 Hrs.							
2	IR 2667	2	268	10:28	12:06	Max 30 min. per passenger	10:29	12:20	Max 118 sec. per passenger	7	-----------
Total Time				01:38 Hrs.			01:21 Hrs.				
Average Time Per Passenger				1 Min			1 Min				
Total Time For All Flight				02:08 Hrs.							
3	NP 151	2	95	10:50	11:10	Max 30 min. per passenger	11:00	11:15	Max 118 sec. per passenger	7	-----------
Total Time				20 Min.			15 Min.				
Average Time Per Passenger				12 Sec.			10 Sec.				
Total Time For All Flight				25 Min.							

Immigration Arrival (Statistic)

Monday 09/05/2011

(Statistic Per passenger)

#	Flight #	Counters #	sex	Actual Time For Queuing Until Counters		MTR	Actual Processing Time At The Counters		MTR	Total staff	Remarks
				Start	Complete		Start	Complete			
1	PK 7561	2	M	18:50	19:19	30 minute	19:20	19:26	118 Sec	5	-----------
Total Time				29 Min			6 Min				
2	SV 2821	2	F	16:38	16:58	30 minute	17:01	17:04	118 Sec	4	-----------
Total Time				20 Min			3 Min				
3	IR 2687	2	M	15:21	16:00	30 minute	16:03	16:08	118 Sec	6	-----------
Total Time				39 Min			5 Min				

(Statistic Per Flight)

#	Flight #	Counters #	Total PAX	Actual Time For Queuing Until Counter		MTR	Actual Processing Time At The Counter		MTR	Total staff	Remarks
				Start	Complete		Start	Complete			
1	PK 7561	2	435	18:50	20:15	Max 30 Min. Per Passenger	19:00	20:19	Max 118 Sec. Per Passenger	5	-----------
Total Time				01:25 Hrs.			01:19 Hrs.				
Average Time Per Passenger				12 Sec			11 Sec				
Total Time For All Flight				01:29 Hrs.							
2	SV 2821	2	280	16:38	17:30	Max 30 Min. Per Passenger	16:30	17:35	Max 118 Sec. Per Passenger	4	-----------
Total Time				52 Min.			55 Min.				
Average Time Per Passenger				11 Sec.			11 Sec.				
Total Time For All Flight				57 Min.							
3	IR 2687	2	267	15:21	16:35	Max 30 Min. Per Passenger	15:28	16:38	Max 118 Sec. Per Passenger	6	-----------
Total Time				01:14 Hrs.			01:10 Hrs.				
Average Time Per Passenger				17 Sec.			17 Sec.				
Total Time For All Flight				01:17 Hrs.							

Immigration Arrival (Statistic)

Tuesday 10/05/2011

(Statistic Per passenger)

#	Flight #	Counters #	sex	Actual Time For Queuing Until Counters		MTR	Actual Processing Time At The Counters		MTR	Total staff	Remarks
				Start	Complete		Start	Complete			
1	GF 171	2	M	13:39	13:55	30 minute	13:56	13:59	118 Sec	2	-----------
Total Time				16 Min			3 Min				
2	IR 2697	2	F	04:03	04:28	30 minute	04:29	04:31	118 Sec	8	-----------
Total Time				25 Min			2 Min				
3	TK 4952	2	F	22:40	03:07	30 minute	23:08	23:11	118 Sec	7	-----------
Total Time				27 Min			3 Min				

(Statistic Per Flight)

#	Flight #	Counters #	Total PAX	Actual Time For Queuing Until Counter		MTR	Actual Processing Time At The Counter		MTR	Total staff	Remarks
				Start	Complete		Start	Complete			
1	GF 171	2	255	13:39	14:25	Max 30 min. per passenger	13:45	14:28	Max 118 sec. per passenger	2	-----------
Total Time				46 Min.			42 Min.				
Average Time Per Passenger				11 Sec.			10 Sec.				
Total Time For All Flight				49 Min.							
2	IR 2697	2	433	04:03	04:52	Max 30 min. per passenger	04:10	04:56	Max 118 sec. per passenger	8	-----------
Total Time				49 Min.			46 Min.				
Average Time Per Passenger				7 Sec.			7 Sec.				
Total Time For All Flight				53 Min.							
3	TK 4952	2	189	22:40	23:22	Max 30 min. per passenger	22:45	23:26	Max 118 sec. per passenger	7	-----------
Total Time				42 Min.			41 Min.				
Average Time Per Passenger				14 Sec.			13 Sec.				
Total Time For All Flight				46 Min.							

Immigration Arrival (Statistic)

Wednesday 11/05/2011

(Statistic Per passenger)

#	Flight #	Counters #	sex	Actual Time For Queuing Until Counters		MTR	Actual Processing Time At The Counters		MTR	Total staff	Remarks
				Start	Complete		Start	Complete			
1	W5 5094	2	M	12:44	12:59	30 minute	13:01	13:04	118 Sec	5	-----------
Total Time				15 Min			3 Min				
2	SV 2311	1	M	12:10	12:41	30 minute	12:44	12:48	118 Sec	4	-----------
Total Time				31 Min			4 Min				
3	6Q 4204	2	F	07:37	08:05	30 minute	08:06	08:11	118 Sec	5	-----------
Total Time				32 Min			5 Min				

(Statistic Per Flight)

#	Flight #	Counters #	Total PAX	Actual Time For Queuing Until Counter		MTR	Actual Processing Time At The Counter		MTR	Total staff	Remarks
				Start	Complete		Start	Complete			
1	W5 5094	2	433	12:44	13:36	Max 30 min. per passenger	12:57	13:41	Max 118 sec. per passenger	5	-----------
Total Time				42 Min.			44 Min.				
Average Time Per Passenger				5 Sec			5 Sec				
Total Time For All Flight				57 Min.							
2	SV 2311	1	320	12:10	13:03	Max 30 min. per passenger	12:31	13:10	Max 118 sec. per passenger	4	-----------
Total Time				57 Min.			39 Min.				
Average Time Per Passenger				6 Sec			6 Sec				
Total Time For All Flight				01:00 Hrs.							
3	6Q 4204	2	144	07:37	08:25	Max 30 min. per passenger	07:41	08:30	Max 118 sec. per passenger	5	-----------
Total Time				48 Min.			49 Min.				
Average Time Per Passenger				20 Sec.			20 Sec.				
Total Time For All Flight				53 Min.							

Immigration Arrival (Statistic)

Thursday 12/05/2011

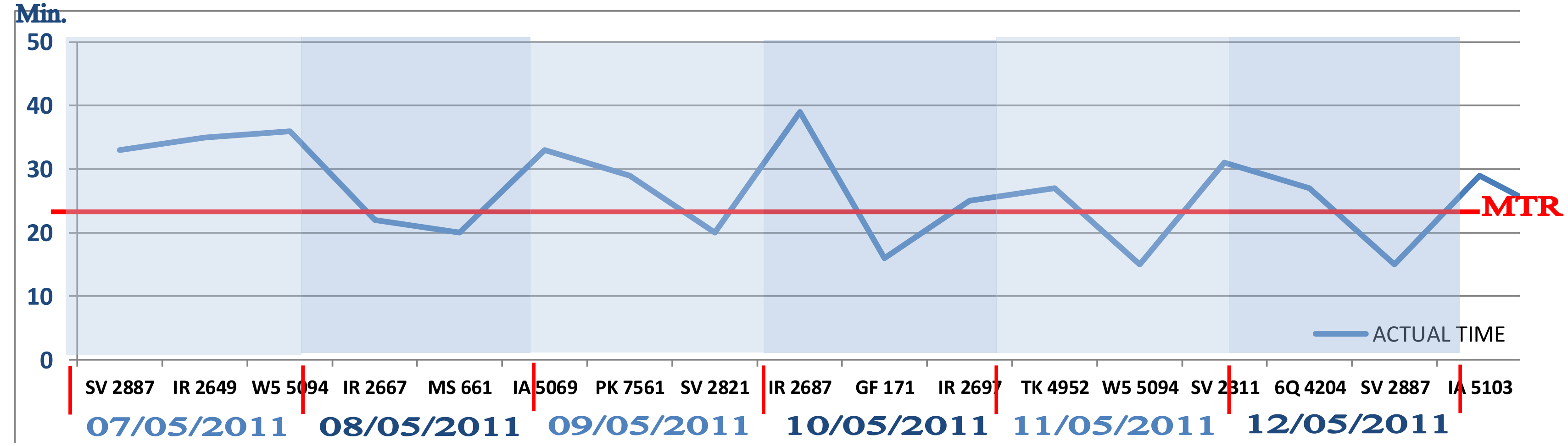
(Statistic Per passenger)

#	Flight #	Counters #	sex	Actual Time For Queuing Until Counters		MTR	Actual Processing Time At The Counters		MTR	Total staff	Remarks
				Start	Complete		Start	Complete			
1	SV 2887	2	M	03:00	03:15	30 minute	03:18	03:21	118 Sec	5	-----------
Total Time				15 Min			3 Min				
2	IA 5103	2	M	17:01	17:30	30 minute	17:32	17:36	118 Sec	7	-----------
Total Time				29 Min			4 Min				
3	IR 2735	1	F	22:00	22:22	30 minute	22:25	22:30	118 Sec	5	-----------
Total Time				22 Min			5 Min				

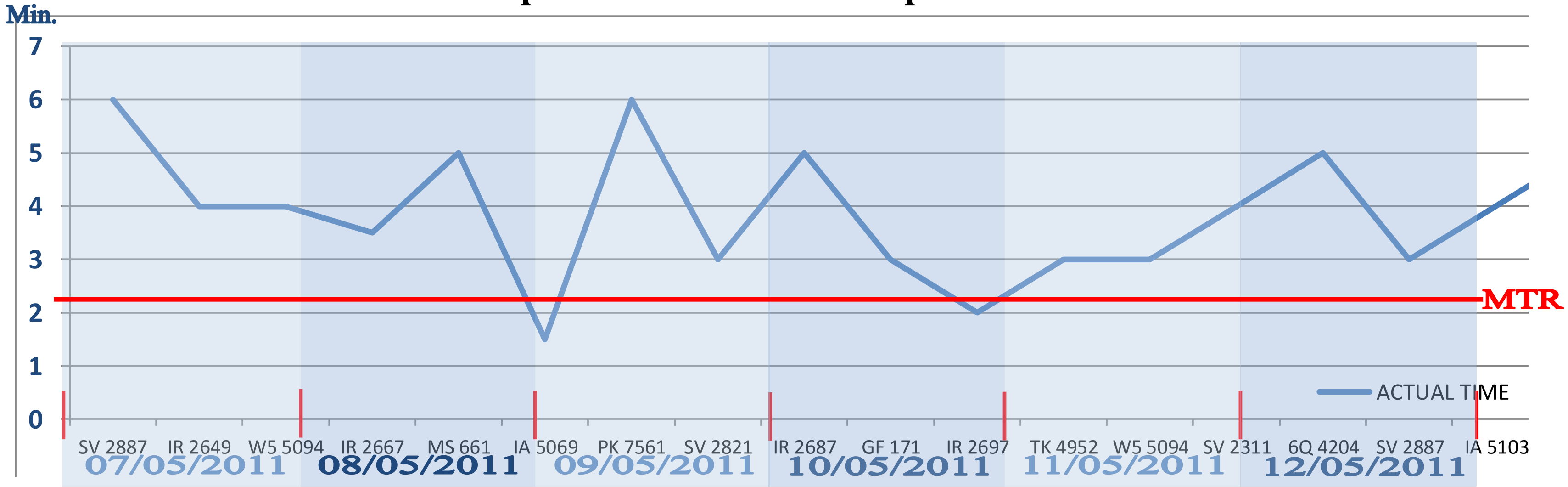
(Statistic Per passenger)

#	Flight #	Counters #	Total PAX	Actual Time For Queuing Until Counter		MTR	Actual Processing Time At The Counter		MTR	Total staff	Remarks
				Start	Complete		Start	Complete			
1	SV 2887	2	289	03:00	03:40	Max 30 min. per passenger	03:10	03:50	Max 118 sec. per passenger	5	-----------
Total Time				40 Min.			40 Min.				
Average Time Per Passenger				8 Sec.			8 Sec.				
Total Time For All Flight				50 Min.							
2	IA 5103	2	420	17:01	18:00	Max 30 min. per passenger	17:25	18:04	Max 118 sec. per passenger	7	-----------
Total Time				59 Min.			39 Min.				
Average Time Per Passenger				9 Sec.			7 Sec.				
Total Time For All Flight				01:03 Hrs.							
3	IR 2735	1	240	22:00	22:50	Max 30 min. per passenger	22:10	22:57	Max 118 sec. per passenger	5	-----------
Total Time				50 Min.			47 Min.				
Average Time Per Passenger				7 Sec.			7 Sec.				
Total Time For All Flight				57 Min.							

Immigration Arrival (Analyzing per passenger)
For the Actual queuing time according to MTR
For the period from 07/05/2011 up to 12/05/2011



Immigration Arrival (Analyzing per passenger)
For the Actual processing time according to MTR
For the period from 07/05/2011 up to 12/05/2011



Immigration Departure (Statistic)

Saturday 07/05/2011

(Statistic Per Passenger)

#	Flight #	Counters #	sex	Actual Time For Queuing Until Counters		MTR	Actual Processing Time At The Counters		MTR	Total staff	Remarks
				Start	Complete		Start	Complete			
1	SV 2616	3	M	03:45	04:19	30 minute	04:19	04:22	118 Sec	2	----------
Total Time				34 Min			3 Min				
2	SV 2866	3	M	05:20	05:44	30 minute	05:46	05:50	118 Sec	2	----------
Total Time				24 Min			4 Min				
3	W5 5093	3	F	10:01	10:35	30 minute	10:40	10:42	118 Sec	3	----------
Total Time				34 Min			2 Min				

(Statistic per Flight)

#	Flight #	Counters #	Total PAX	Actual Time For Queuing Until Counter		MTR	Actual Processing Time At The Counter		MTR	Total staff	Remarks
				Start	Complete		Start	Complete			
1	SV 2616	3	316	03:45	06:30	Max 30 min. per passenger	04:19	06:33	Max 118 sec. per passenger	2	----------
Total Time				02:45 Hrs.			02:14 Hrs.				
Average Time Per Passenger				31 Sec.			31 Sec.				
Total Time For All Flight				02:48 Hrs.							
2	SV 2866	3	294	05:20	08:52	Max 30 min. per passenger	05:44	08:55	Max 118 sec. per passenger	2	----------
Total Time				03:32 Hrs.			03:11 Hrs.				
Average Time Per Passenger				1 Min.			1 Min.				
Total Time For All Flight				03:35 Hrs.							
3	W5 5093	3	430	10:01	12:06	Max 30 min. per passenger	10:25	12:10	Max 118 sec. per passenger	3	----------
Total Time				02:05 Hrs.			02:15 Hrs.				
Average Time Per Passenger				18 Sec.			18 Sec.				
Total Time For All Flight				02:09 Hrs.							

Immigration Departure (Statistic)

Sunday 08/05/2011

(Statistic Per passenger)

#	Flight #	Counters #	sex	Actual Time For Queuing Until Counters		MTR	Actual Processing Time At The Counters		MTR	Total staff	Remarks
				Start	Complete		Start	Complete			
1	W5 5083	3	M	10:49	11:01	30 minute	11:02	11:03	118 Sec	3	-----------
Total Time				12 Min			1 Min				
2	IA 5074	3	F	13:59	14:08	30 minute	14:09	14:11	118 Sec	2	-----------
Total Time				09 Min			2 Min				
3	EY 312	3	M	13:59	14:29	30 minute	14:31	14:33	118 Sec	2	-----------
Total Time				30 Min			2 Min				

(Statistic Per passenger)

#	Flight #	Counters #	Total PAX	Actual Time For Queuing Until Counter		MTR	Actual Processing Time At The Counter		MTR	Total staff	Remarks
				Start	Complete		Start	Complete			
1	W5 5083	3	430	10:43	12:55	Max 30 min. per passenger	10:45	13:04	Max 118 sec. per passenger	3	-----------
Total Time				02:12 Hrs.			02:19 Hrs.				
Average Time Per Passenger				33 Sec			34 Min				
Total Time For All Flight				02:21 Hrs.							
2	IA 5074	3	420	13:20	17:25	Max 30 min. per passenger	13:21	17:32	Max 118 sec. per passenger	2	-----------
Total Time				04:05 Hrs.			04:11 Hrs.				
Average Time Per Passenger				58 Sec.			59 Sec.				
Total Time For All Flight				04:12 Hrs.							
3	EY 312	3	186	13:59	16:40	Max 30 min. per passenger	14:02	16:44	Max 118 sec. per passenger	2	-----------
Total Time				02:41 Hrs.			02:42 Hrs.				
Average Time Per Passenger				1 Min			1 Min				
Total Time For All Flight				02:45 Hrs.							

Immigration Departure (Statistic)

Monday 09/05/2011

(Statistic Per passenger)

#	Flight #	Counters #	sex	Actual Time For Queuing Until Counters		MTR	Actual Processing Time At The Counters		MTR	Total staff	Remarks
				Start	Complete		Start	Complete			
1	TK 093	3	M	13:34	13:52	30 minute	13:44	13:50	118 Sec	3	-----------
Total Time				12 Min			1 Min				
2	PK 742	3	F	13:35	13:41	30 minute	13:43	13:49	118 Sec	3	-----------
Total Time				09 Min			2 Min				
3	IA 5082	3	F	13:36	13:49	30 minute	13:48	13:56	118 Sec	4	-----------
Total Time				30 Min			2 Min				

(Statistic Per passenger)

#	Flight #	Counters #	Total PAX	Actual Time For Queuing Until Counter		MTR	Actual Processing Time At The Counter		MTR	Total staff	Remarks
				Start	Complete		Start	Complete			
1	TK 093	3	80	12:08	13:58	Max 30 min. per passenger	12:14	14:00	Max 118 sec. per passenger	3	-----------
Total Time				01:50 Hrs.			01:45 Hrs.				
Average Time Per Passenger				1.5 Min.			1.5 Min.				
Total Time For All Flight				01:52 Hrs.							
2	PK 742	3	420	11:10	14:02	Max 30 min. per passenger	11:14	14:05	Max 118 sec. per passenger	3	-----------
Total Time				02:52 Hrs.			02:50 Hrs.				
Average Time Per Passenger				24 Sec.			24 Sec.				
Total Time For All Flight				02:55 Hrs.							
3	IA 5082	3	396	11:42	13:41	Max 30 min. per passenger	11:45	14:11	Max 118 sec. per passenger	4	-----------
Total Time				02:01 Hrs.			02:26 Hrs.				
Average Time Per Passenger				18 Sec.			19 Sec.				
Total Time For All Flight				02:29 Hrs.							

Immigration Departure (Statistic)

Tuesday 10/05/2011

(Statistic Per passenger)

#	Flight #	Counters #	sex	Actual Time For Queuing Until Counters		MTR	Actual Processing Time At The Counters		MTR	Total staff	Remarks
				Start	Complete		Start	Complete			
1	TK 095	3	M	23:06	23:16	30 minute	23:17	23:20	118 Sec	2	-----------
Total Time				10 Min			3 Min				
2	MS 664	3	M	00:10	00:33	30 minute	00:35	00:40	118 Sec	3	-----------
Total Time				23 Min			5 Min				
3	SV 2836	3	F	17:10	17:40	30 minute	17:42	17:44	118 Sec	3	-----------
Total Time				30 Min			2 Min				

(Statistic Per passenger)

#	Flight #	Counters #	Total PAX	Actual Time For Queuing Until Counter		MTR	Actual Processing Time At The Counter		MTR	Total staff	Remarks
				Start	Complete		Start	Complete			
1	TK 095	3	85	23:06	02:17	Max 30 min. per passenger	23:16	02:19	Max 118 sec. per passenger	2	-----------
Total Time				03:11 Hrs.			03:03 Hrs.				
Average Time Per Passenger				2 Min.			2 Min.				
Total Time For All Flight				03:13 Hrs.							
2	MS 664	3	307	00:10	02:25	Max 30 min. per passenger	00:22	02:28	Max 118 sec. per passenger	3	-----------
Total Time				02:15 Hrs.			02:06 Hrs.				
Average Time Per Passenger				26 Sec.			24 Sec.				
Total Time For All Flight				02:18 Hrs.							
3	SV 2836	3	296	17:10	18:56	Max 30 min. per passenger	17:30	19:00	Max 118 sec. per passenger	3	-----------
Total Time				01:46 Hrs.			01:30 Hrs.				
Average Time Per Passenger				20 Sec.			20 Sec.				
Total Time For All Flight				02:50 Hrs.							

Immigration Departure (Statistic)

Wednesday 11/05/2011

(Statistic Per passenger)

#	Flight #	Counters #	sex	Actual Time For Queuing Until Counters		MTR	Actual Processing Time At The Counters		MTR	Total staff	Remarks
				Start	Complete		Start	Complete			
1	SV 2872	3	M	19:10	19:30	30 minute	19:33	19:35	118 Sec	2	----------
Total Time				20 Min			2 Min				
2	AI 930	3	M	22:21	22:32	30 minute	22:33	22:38	118 Sec	2	----------
Total Time				11 Min			5 Min				
3	MS 664	3	F	23:18	23:28	30 minute	23:30	23:37	118 Sec	3	----------
Total Time				10 Min			7 Min				

(Statistic Per passenger)

#	Flight #	Counters #	Total PAX	Actual Time For Queuing Until Counter		MTR	Actual Processing Time At The Counter		MTR	Total staff	Remarks
				Start	Complete		Start	Complete			
1	SV 2872	3	442	19:10	20:39	Max 30 min. per passenger	19:25	20:42	Max 118 sec. per passenger	2	----------
Total Time				01:29 Hrs.			01:17 Hrs.				
Average Time Per Passenger				12 Sec			9 Sec				
Total Time For All Flight				01:32 Hrs.							
2	AI 930	3	150	22:21	01:07	Max 30 min. per passenger	22:23	01:10	Max 118 sec. per passenger	2	----------
Total Time				02:46 Hrs.			02:47 Hrs.				
Average Time Per Passenger				1 Min.			1 Min.				
Total Time For All Flight				02:49 Hrs.							
3	MS 664	3	280	23:18	02:25	Max 30 min. per passenger	23:25	02:30	Max 118 sec. per passenger	3	----------
Total Time				03:07 Hrs.			03:05 Hrs.				
Average Time Per Passenger				1.5 Min			1.5 Min				
Total Time For All Flight				03:12 Hrs.							

Immigration Departure (Statistic)

Thursday 12/05/2011

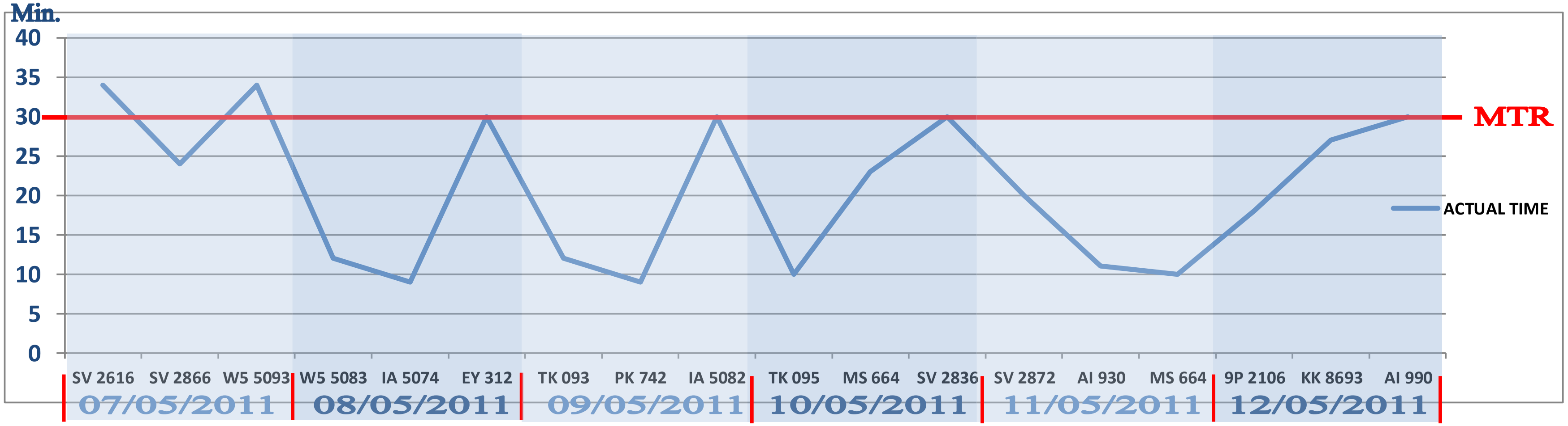
(Statistic Per passenger)

#	Flight #	Counters #	sex	Actual Time For Queuing Until Counters		MTR	Actual Processing Time At The Counters		MTR	Total staff	Remarks
				Start	Complete		Start	Complete			
1	9P 2106	4	M	09:00	09:18	30 minute	09:19	09:23	118 Sec	2	-----------
Total Time				18 Min			4 Min				
2	KK 8693	3	M	16:55	17:22	30 minute	17:25	17:31	118 Sec	3	-----------
Total Time				27 Min			6 Min				
3	AI 990	4	F	00:20	00:50	30 minute	00:52	05:59	118 Sec	2	-----------
Total Time				30 Min			7 Min				

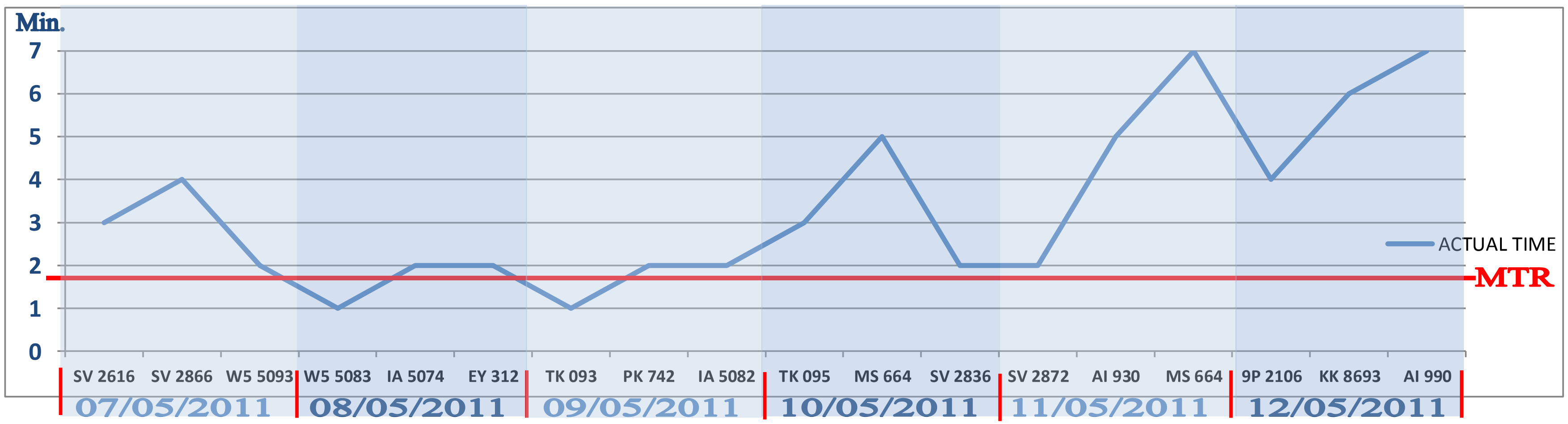
(Statistic Per passenger)

#	Flight #	Counters #	Total PAX	Actual Time For Queuing Until Counter		MTR	Actual Processing Time At The Counter		MTR	Total staff	Remarks
				Start	Complete		Start	Complete			
1	9P 2106	4	165	09:00	10:08	Max 30 min. per passenger	09:10	10:14	Max 118 sec. per passenger	2	-----------
Total Time				01:08 Hrs.			01:04 Hrs.				
Average Time Per Passenger				24 Sec			24 Sec				
Total Time For All Flight				01:14 Hrs.							
2	KK 8693	3	275	16:55	18:56	Max 30 min. per passenger	17:08	19:00	Max 118 sec. per passenger	3	-----------
Total Time				02:01 Hrs.			01:52 Hrs.				
Average Time Per Passenger				26 Sec.			24 Sec.				
Total Time For All Flight				02:05 Hrs.							
3	AI 990	4	210	00:20	01:40	Max 30 min. per passenger	00:45	01:47	Max 118 sec. per passenger	2	-----------
Total Time				01:20 Hrs.			01:02 Hrs.				
Average Time Per Passenger				22 Sec.			22 Sec.				
Total Time For All Flight				01:27 Hrs.							

Immigration Departure (Analyzing per passenger)
For the Actual Queuing Time According to MTR
For the period from 07/05/2011 up to 12/05/2011



Immigration Departure (Analyzing per passenger)
For the Actual Processing Time According to MTR
For the period from 07/05/2011 up to 12/05/2011



General comments of Immigration

1- Staff shortages .

2- Sometimes late report of the staff due to shift change while passengers waiting in front of the counters.

3- Sometimes immigration staffs have their meals while passengers waiting in front of the counters.

Check in Area (Statistic)

Saturday 07/05/2011

(Statistic Per Passenger)

#	Flight #	Belt	sex	Actual Time For Queuing Until Counters		MTR	Actual Processing Time At The Counters		MTR	Total staff	Remarks
				Start	Complete		Start	Complete			
1	SV 403	L-1	M	23:21	23:48	20 minute	23:49	23:57	05 minute	4	----------
Total Time				17 Min			08 Min				
2	TK 4593	L-5	F	06:35	06:58	20 minute	07:02	07:07	05 minute	4	----------
Total Time				23 Min			05 Min				
3	IR 2652	L-4	F	05:57	07:23	20 minute	07:26	07:35	05 minute	5	----------
Total Time				26 Min			09 Min				

(Statistic Per Flight)

#	Flight #	Belt	Total PAX	Actual time for queuing until counter		MTR	Actual processing time at the counter		MTR	Total staff	Remarks
				Start	Complete		Start	Complete			
1	SV 403	L-1	183	23:21	03:08	Max 20 min. per passenger	23:30	03:16	Max 05 min. per passenger	4	----------
Total Time				03:49 Hrs.			03:46 Hrs.				
Average Time Per Passenger				1.30 Min			1.30 Min				
Total Time For All Flight				04:06 Hrs.							
2	TK 4593	L-5	264	06:35	08:49	Max 20 min. per passenger	06:40	08:55	Max 05 min. per passenger	4	----------
Total Time				02:24 Hrs.			02:15 Hrs.				
Average Time Per Passenger				1 Min			1 Min				
Total Time For All Flight				02:30 Hrs.							
3	IR 2652	L-4	243	06:57	09:15	Max 20 min. per passenger	07:02	09:18	Max 05 min. per passenger	5	----------
Total Time				02:16 Hrs.			02:18 Hrs.				
Average Time Per Passenger				1 Min			1 Min				
Total Time For All Flight				02:23 Hrs.							

Check in Area (Statistic)

Sunday 08/05/2011

(Statistic Per Passenger)

#	Flight #	Belt	sex	Actual Time For Queuing Until Counters		MTR	Actual Processing Time At The Counters		MTR	Total staff	Remarks
				Start	Complete		Start	Complete			
1	TK 4611	L-2	F	09:41	10:09	20 minute	10:09	10:10	05 minute	5	-----------
Total Time				28 Min			01 Min				
2	TK 093	L-2	M	11:11	11:25	20 minute	11:26	11:28	05 minute	3	-----------
Total Time				14 Min			02 Min				
3	W5 5083	L-2	F	10:55	12:00	20 minute	12:00	12:05	05 minute	4	-----------
Total Time				65 Min			05 Min				

(Statistic Per Flight)

#	Flight #	Belt	Total PAX	Actual time for queuing until counter		MTR	Actual processing time at the counter		MTR	Total staff	Remarks
				Start	Complete		Start	Complete			
1	TK 093	L-2	210	11:11	13:56	Max 20 min. per passenger	11:26	14:00	Max 05 min. per passenger	5	-----------
Total Time				02:45 Hrs.			02:34 Hrs.				
Average Time Per Passenger				47 Sec.			44 Sec.				
Total Time For All Flight				02:49 Hrs.							
2	SV 2804	L-1	290	14:30	15:31	Max 20 min. per passenger	14:35	15:35	Max 05 min. per passenger	3	-----------
Total Time				01:01 Hrs.			01:00 Hrs.				
Average Time Per Passenger				13 Sec.			12 Sec.				
Total Time For All Flight				01:05 Hrs.							
3	GA 980	L-2	400	14:40	16:58	Max 20 min. per passenger	14:58	17:10	Max 05 min. per passenger	4	-----------
Total Time				02:18 Hrs.			02:12 Hrs.				
Average Time Per Passenger				20 Sec.			19 Sec.				
Total Time For All Flight				02:30 Hrs.							

Check in Area (Statistic)

Monday 09/05/2011

(Statistic Per Passenger)

#	Flight #	Belt	sex	Actual Time For Queuing Until Counters		MTR	Actual Processing Time At The Counters		MTR	Total staff	Remarks
				Start	Complete		Start	Complete			
1	UJ 902	L-6	F	14:05	14:59	20 minute	15:00	15:09	05 minute	3	----------
Total Time				54 Min			9 Min				
2	PK 7562	L-6	M	15:37	17:00	20 minute	17:01	17:11	05 minute	2	----------
Total Time				23 Min			10 Min				
3	PK 732	L-6	M	18:40	19:20	20 minute	19:22	19:31	05 minute	4	----------
Total Time				40 Min			08 Min				

(Statistic Per Flight)

#	Flight #	Belt	Total PAX	Actual time for queuing until counter		MTR	Actual processing time at the counter		MTR	Total staff	Remarks
				Start	Complete		Start	Complete			
1	UJ 902	L-6	103	14:05	15:50	Max 20 min. per passenger	14:15	15:59	Max 05 min. per passenger	3	----------
Total Time				01:45 Hrs.			01:44				
Average Time Per Passenger				1 Min.			1 Min.				
Total Time For All Flight				01:54 Hrs.							
2	PK 7562	L-6	214	14:10	17:30	Max 20 min. per passenger	14:50	17:40	Max 05 min. per passenger	2	----------
Total Time				03:20 Hrs.			02:10 Hrs.				
Average Time Per Passenger				20 Sec.			19 Sec.				
Total Time For All Flight				03:30 Hrs.							
3	PK 732	L-6	430	15:37	17:41	Max 20 min. per passenger	15:39	17:53	Max 05 min. per passenger	4	----------
Total Time				02:04 Hrs.			02:14				
Average Time Per Passenger				17.5 Sec.			18.5 Sec.				
Total Time For All Flight				02:16 Hrs.							

Check in Area (Statistic)

Tuesday 10/05/2011

(Statistic Per Passenger)

#	Flight #	Belt	sex	Actual Time For Queuing Until Counters		MTR	Actual Processing Time At The Counters		MTR	Total staff	Remarks
				Start	Complete		Start	Complete			
1	IR 2698	L-4	M	00:30	00:57	20 minute	00:58	01:07	05 minute	4	-----------
Total Time				27 Min			9 Min				
2	IA 5090	L-3	M	11:25	12:02	20 minute	12:04	12:09	05 minute	5	-----------
Total Time				37 Min			6 Min				
3	TU 6806	L-5	F	21:08	21:31	20 minute	21:25	21:32	05 minute	5	-----------
Total Time				23 Min			7 Min				

(Statistic Per Flight)

#	Flight #	Belt	Total PAX	Actual time for queuing until counter		MTR	Actual processing time at the counter		MTR	Total staff	Remarks
				Start	Complete		Start	Complete			
1	IR 2698	L-4	420	00:30	02:37	Max 20 min. per passenger	00:40	02:40	Max 05 min. per passenger	4	-----------
Total Time				02:07 Hrs.			02:00 Hrs.				
Average Time Per Passenger				18 Sec.			18 Sec.				
Total Time For All Flight				02:10 Hrs.							
2	IA 5090	L-3	410	11:25	13:55	Max 20 min. per passenger	11:35	13:58	Max 05 min. per passenger	5	-----------
Total Time				02:30 Hrs.			02:33 Hrs.				
Average Time Per Passenger				22 Sec.			22 Sec.				
Total Time For All Flight				02:33 Hrs.							
3	TU 6806	L-5	280	21:08	22:30	Max 20 min. per passenger	21:15	22:35	Max 05 min. per passenger	5	-----------
Total Time				01:22 Hrs.			01:20 Hrs.				
Average Time Per Passenger				18 Sec.			18 Sec.				
Total Time For All Flight				01:27 Hrs.							

Check in Area (Statistic)

Wednesday 11/05/2011

(Statistic Per Passenger)

#	Flight #	Belt	sex	Actual Time For Queuing Until Counters		MTR	Actual Processing Time At The Counters		MTR	Total staff	Remarks
				Start	Complete		Start	Complete			
1	IR 2720	L-6	M	13:40	14:08	20 minute	14:09	14:47	05 minute	4	-----------
Total Time				28 Min			8 Min				
2	SV 2880	L-2	M	04:30	04:44	20 minute	04:47	14:51	05 minute	5	-----------
Total Time				24 Min			4 Min				
3	6Q 4205	L-3	F	05:52	06:05	20 minute	06:07	06:31	05 minute	3	-----------
Total Time				13 Min			6 Min				

(Statistic Per Flight)

#	Flight #	Belt	Total PAX	Actual time for queuing until counter		MTR	Actual processing time at the counter		MTR	Total staff	Remarks
				Start	Complete		Start	Complete			
1	IR 2720	L-6	244	13:40	15:25	Max 20 min. per passenger	13:44	15:31	Max 05 min. per passenger	4	-----------
Total Time				02:15 Hrs.			02:07 Hrs.				
Average Time Per Passenger				33 Sec.			31.5 Sec.				
Total Time For All Flight				02:31 Hrs.							
2	SV 2880	L-2	274	04:30	06:07	Max 20 min. per passenger	04:41	06:19	Max 05 min. per passenger	5	-----------
Total Time				02:07 Hrs.			02:22 Hrs.				
Average Time Per Passenger				28 Sec.			26.5 Sec.				
Total Time For All Flight				02:39 Hrs.							
3	6Q 4205	L-3	151	05:52	07:10	Max 20 min. per passenger	05:06	07:12	Max 05 min. per passenger	3	-----------
Total Time				01:58 Hrs.			02:06 Hrs.				
Average Time Per Passenger				46 Sec.			46 Sec.				
Total Time For All Flight				02:00 Hrs.							

Check in Area (Statistic)

Thursday 12/05/2011

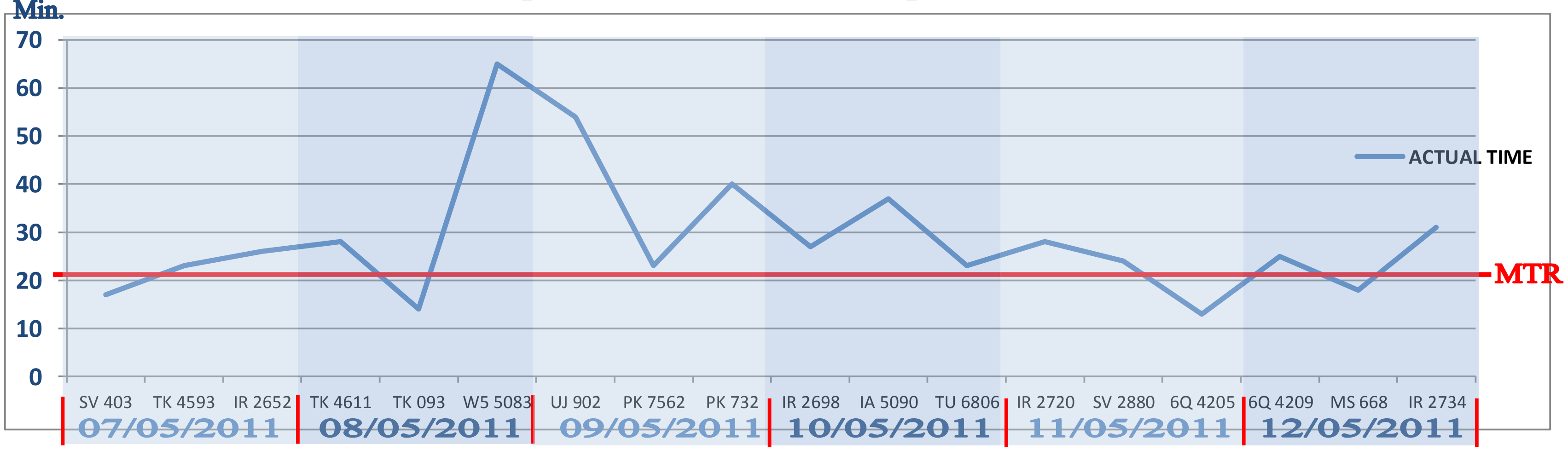
(Statistic Per Passenger)

#	Flight #	Belt	sex	Actual Time For Queuing Until Counters		MTR	Actual Processing Time At The Counters		MTR	Total staff	Remarks
				Start	Complete		Start	Complete			
1	6Q 4209	L-3	M	05:05	05:30	20 minute	05:33	05:39	05 minute	5	-----------
Total Time				25 Min			6 Min				
2	MS 668	L-2	M	10:00	10:18	20 minute	10:21	10:24	05 minute	4	-----------
Total Time				18 Min			3 Min				
3	IR 2734	L-6	F	11:25	11:56	20 minute	12:01	12:04	05 minute	4	-----------
Total Time				31 Min			3 Min				

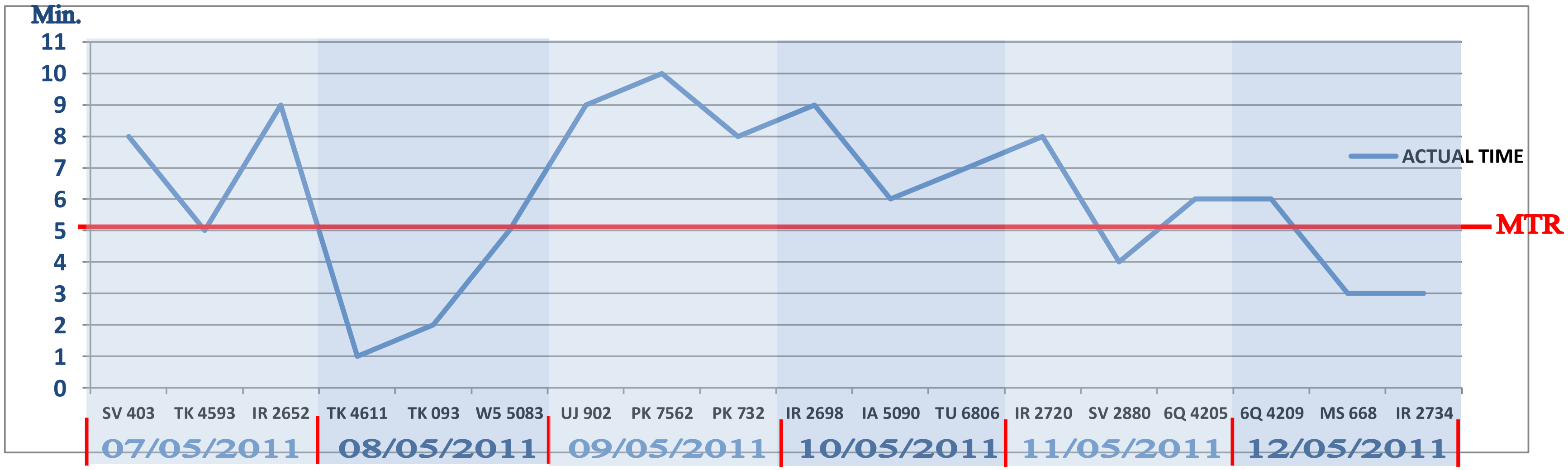
(Statistic Per Flight)

#	Flight #	Belt	Total PAX	Actual time for queuing until counter		MTR	Actual processing time at the counter		MTR	Total staff	Remarks
				Start	Complete		Start	Complete			
1	6Q 4209	L-3	126	05:05	06:19	Max 20 min. per passenger	05:20	06:23	Max 05 min. per passenger	5	-----------
Total Time				01:14 Hrs.			01:03 Hrs.				
Average Time Per Passenger				35 Sec.			33.5 Sec.				
Total Time For All Flight				01:18 Hrs.							
2	MS 668	L-2	68	10:00	12:37	Max 20 min. per passenger	10:10	12:42	Max 05 min. per passenger	4	-----------
Total Time				02:37 Hrs.			02:32 Hrs.				
Average Time Per Passenger				2.5 Min.			2.5 Min.				
Total Time For All Flight				02:42 Hrs.							
3	IR 2734	L-6	431	11:25	13:35	Max 20 min. per passenger	11:38	13:48	Max 05 min. per passenger	4	-----------
Total Time				02:10 Hrs.			02:10 Hrs.				
Average Time Per Passenger				18.5 Sec			18.5 Sec				
Total Time For All Flight				02:23 Hrs.							

Check in Area (Analyzing per passenger)
For the Actual Queuing Time According to MTR
For the period from 07/05/2011 up to 12/05/2011



Check in Area (Analyzing per passenger)
For the Actual processing Time According to MTR
For the period from 07/05/2011 up to 12/05/2011



General Comments of the Check in Area

- **The Ground Handling Agent Comments :**

1- Staff shortages.
2- Labors/Equipment shortages.
3- No staff / labors during shift change.
4- No update for flights information in case the delay. CCO have to search for the information.
5- Misuse of equipment's.
6- Staffs do not keep work area clean.
7- They keep the airlines stationery scattered behind check-in counters.
8- Staff not available at check-in modules entrance to control passengers movement and baggage size & Wight .

- **Airlines:**

1- Not complying with (IATA) passengers baggage weight & size regulations .

Passengers Security Check at lounges (GID) (Statistic)

Saturday 07/05/2011

(Statistic Per Passenger)

#	Flight #	Lunge	sex	Actual Time For Queuing Until the X-ray		MTR	Actual Processing Time At The X-ray		MTR	Total staff	Remarks
				Start	Complete		Start	Complete			
1	W5 5001	6	M	09:44	09:49	10 minute	09:50	09:52	20 Sec.	4	-----------
Total Time				5 MIN			120 Sec.				
2	TK 4609	7	M	10:05	10:30	10 minute	10:31	10:32	20 Sec.	3	-----------
Total Time				25 MIN			60 Sec.				
3	SV 2804	7	F	14:55	14:59	10 minute	15:03	15:05	20 Sec.	3	-----------
Total Time				4 MIN			120 Sec.				

(Statistic Per Flight)

#	Flight #	Lounge	Total PAX	Actual Time For Queuing Until the X-ray		MTR	Actual Processing Time At The X-ray		MTR	Total staff	Remarks
				Start	Complete		Start	Complete			
1	TK 4611	5	194	10:01	10:35	Max 10 min. per passenger	10:26	11:15	20 Sec.	4	-----------
Total Time				49 Min.			34 Min.				
Average Time Per Passenger				15 Sec.			10 Sec.				
Total Time For All Flight				01:14 Hrs.							
2	W5 5083	7	129	10:59	12:45	Max 10 min. per passenger	11:05	12:54	20 Sec.	3	-----------
Total Time				01:46 Hrs.			01:49 Hrs.				
Average Time Per Passenger				49 Sec.			50 Sec.				
Total Time For All Flight				01:14 Hrs.							
3	EY 312	5	335	14:16	17:09	Max 10 min. per passenger	14:28	17:10	20 Sec.	4	-----------
Total Time				02:55 Hrs.			02:44 Hrs.				
Average Time Per Passenger				31 Sec.			29 Sec.				
Total Time For All Flight				03:00 Hrs.							

Passengers Security Check at lounges (GID) (Statistic)

Sunday 08/05/2011

(Statistic Per Passenger)

#	Flight #	Lunge	sex	Actual Time For Queuing Until the X-ray		MTR	Actual Processing Time At The X-ray		MTR	Total staff	Remarks
				Start	Complete		Start	Complete			
1	W5 5001	6	M	09:44	09:49	10 minute	09:50	09:52	20 Sec.	4	-----------
Total Time				5 MIN			120 Sec.				
2	TK 4609	7	M	10:05	10:30	10 minute	10:31	10:32	20 Sec.	3	-----------
Total Time				25 MIN			60 Sec.				
3	SV 2804	7	F	14:55	14:59	10 minute	15:03	15:05	20 Sec.	3	-----------
Total Time				4 MIN			120 Sec.				

(Statistic Per Flight)

#	Flight #	Lounge	Total PAX	Actual Time For Queuing Until the X-ray		MTR	Actual Processing Time At The X-ray		MTR	Total staff	Remarks
				Start	Complete		Start	Complete			
1	TK 4611	5	194	10:01	10:35	Max 10 min. per passenger	10:26	11:15	20 Sec.	4	-----------
Total Time				49 Min.			34 Min.				
Average Time Per Passenger				15 Sec.			10 Sec.				
Total Time For All Flight				01:14 Hrs.							
2	W5 5083	7	129	10:59	12:45	Max 10 min. per passenger	11:05	12:54	20 Sec.	3	-----------
Total Time				01:46 Hrs.			01:49 Hrs.				
Average Time Per Passenger				49 Sec.			50 Sec.				
Total Time For All Flight				01:14 Hrs.							
3	EY 312	5	335	14:16	17:09	Max 10 min. per passenger	14:28	17:10	20 Sec.	4	-----------
Total Time				02:55 Hrs.			02:44 Hrs.				
Average Time Per Passenger				31 Sec.			29 Sec.				
Total Time For All Flight				03:00 Hrs.							

Passengers Security Check at lounges (GID) (Statistic)

Monday 09/05/2011

(Statistic Per Passenger)

#	Flight #	Lunge	sex	Actual Time For Queuing Until the X-ray		MTR	Actual Processing Time At The X-ray		MTR	Total staff	Remarks
				Start	Complete		Start	Complete			
1	W5 5091	5	M	07:50	08:25	10 minute	08:27	08:33	20 Sec.	3	-----------
Total Time				35 MIN			360 Sec.				
2	MS 674	14	F	02:40	03:06	10 minute	03:09	03:13	20 Sec.	4	-----------
Total Time				26 MIN			240 Sec.				
3	IA 5082	9	M	11:35	12:09	10 minute	12:11	12:12	20 Sec.	3	-----------
Total Time				34 MIN			60 Sec				

(Statistic Per Flight)

#	Flight #	Lounge	Total PAX	Actual Time For Queuing Until the X-ray		MTR	Actual Processing Time At The X-ray		MTR	Total staff	Remarks
				Start	Complete		Start	Complete			
1	W5 5091	5	248	07:50	09:51	Max 10 min. per passenger	08:27	10:00	20 Sec.	4	-----------
Total Time				02:01 Hrs.			02:13 Hrs.				
Average Time Per Passenger				29 Sec.			29 Sec.				
Total Time For All Flight				02:50 Hrs.							
2	MS 674	14	118	02:40	03:40	Max 10 min. per passenger	03:10	03:44	20 Sec.	3	-----------
Total Time				01:00 Hrs.			34 Min.				
Average Time Per Passenger				30 Sec.			17.5 Sec				
Total Time For All Flight				01:04 Hrs.							
3	IA 5082	9	254	11:35	14:07	Max 10 min. per passenger	12:11	14:32	20 Sec.	4	-----------
Total Time				03:12 Hrs.			02:21Hrs.				
Average Time Per Passenger				45.5 Sec.			33.5 Sec.				
Total Time For All Flight				03:37 Hrs.							

Passengers Security Check at lounges (GID) (Statistic)

Tuesday 10/05/2011

(Statistic Per Passenger)

#	Flight #	Lunge	sex	Actual Time For Queuing Until the X-ray		MTR	Actual Processing Time At The X-ray		MTR	Total staff	Remarks
				Start	Complete		Start	Complete			
1	SV 2830	13	M	19:05	19:28	10 minute	19:33	19:39	20 Sec.	4	-----------
Total Time				23 MIN			360 Sec.				
2	GA 983	8	F	22:40	22:56	10 minute	22:57	22:59	20 Sec.	4	-----------
Total Time				16 MIN			120 Sec.				
3	TU 6806	13	M	22:01	22:22	10 minute	22:23	22:25	20 Sec.	4	-----------
Total Time				21 MIN			120 Sec.				

(Statistic Per Flight)

#	Flight #	Lounge	Total PAX	Actual Time For Queuing Until the X-ray		MTR	Actual Processing Time At The X-ray		MTR	Total staff	Remarks
				Start	Complete		Start	Complete			
1	SV 2830	13	442	19:05	21:50	Max 10 min. per passenger	19:20	21:56	20 Sec.	4	-----------
Total Time				02:45 Hrs.			02:36 Hrs.				
Average Time Per Passenger				22.5 Sec.			21 Sec.				
Total Time For All Flight				02:51 Hrs.							
2	GA 983	8	300	22:40	23:38	Max 10 min. per passenger	22:47	23:42	20 Sec.	4	-----------
Total Time				01:38 Hrs.			01:35				
Average Time Per Passenger				31 Sec			30.5 Sec				
Total Time For All Flight				01:37 Hrs.							
3	TU 6806	13	265	22:01	22:57	Max 10 min. per passenger	22:19	23:00	20 Sec.	4	-----------
Total Time				56 Min.			01:21 Hrs.				
Average Time Per Passenger				11 Sec.			12.5 Sec.				
Total Time For All Flight				01:39 Hrs.							

Passengers Security Check at lounges (GID) (Statistic)

Wednesday 11/05/2011

(Statistic Per Passenger)

#	Flight #	Lunge	sex	Actual Time For Queuing Until the X-ray		MTR	Actual Processing Time At The X-ray		MTR	Total staff	Remarks
				Start	Complete		Start	Complete			
1	IA 5092	5	F	23:01	23:16	10 minute	23:18	23:22	20 Sec.	4	-----------
Total Time				15 MIN			240 Sec.				
2	W5 5003	5	M	07:10	07:29	10 minute	07:32	07:37	20 Sec.	4	-----------
Total Time				19 MIN			300 Sec				
3	KK 8691	7	M	18:45	19:00	10 minute	19:02	19:05	20 Sec.	5	-----------
Total Time				15 MIN			180 Sec.				

(Statistic Per Flight)

#	Flight #	Lounge	Total PAX	Actual Time For Queuing Until the X-ray		MTR	Actual Processing Time At The X-ray		MTR	Total staff	Remarks
				Start	Complete		Start	Complete			
1	IA 5092	5	134	23:01	00:28	Max 10 min. per passenger	23:15	00:32	20 Sec.	4	-----------
Total Time				01:29 Hrs.			01:17 Hrs.				
Average Time Per Passenger				39 Sec.			34 Sec.				
Total Time For All Flight				01:31 Hrs.							
2	W5 5003	5	243	07:10	07:57	Max 10 min. per passenger	07:15	08:04	20 Sec.	4	-----------
Total Time				01:34 Hrs.			01:29 Hrs.				
Average Time Per Passenger				38 Sec.			22 Sec.				
Total Time For All Flight				01:34 Hrs.							
3	KK 8691	7	324	18:45	20:10	Max 10 min. per passenger	18:55	20:20	20 Sec.	5	-----------
Total Time				02:05 Hrs.			02:05				
Average Time Per Passenger				23 Sec			23 Sec				
Total Time For All Flight				02:15 Hrs.							

Passengers Security Check at lounges (GID) (Statistic)

Thursday 12/05/2011

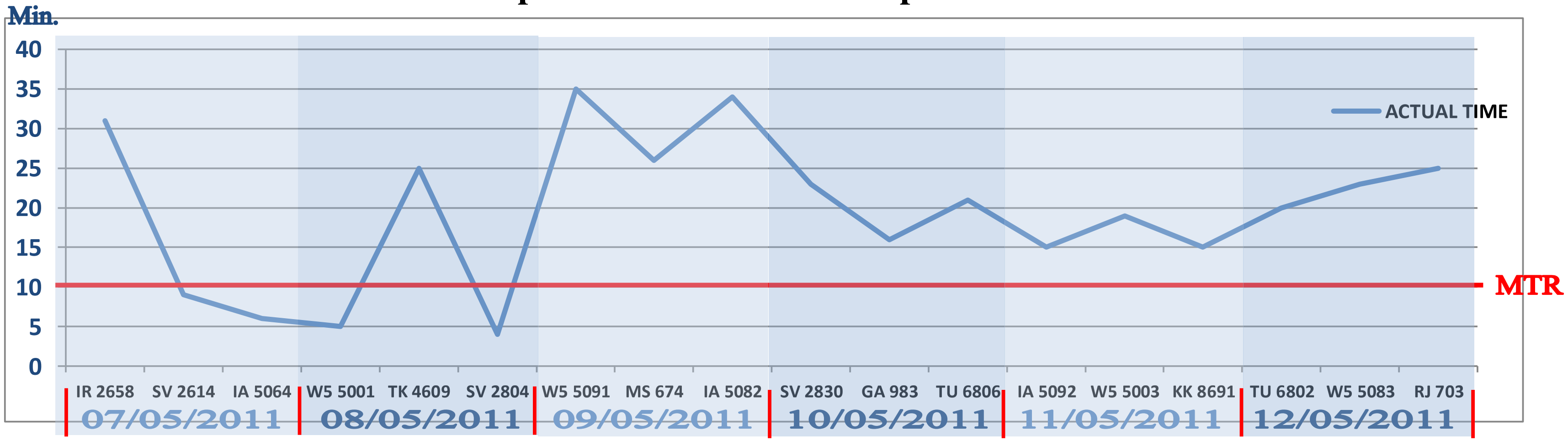
(Statistic Per Passenger)

#	Flight #	Lunge	sex	Actual Time For Queuing Until the X-ray		MTR	Actual Processing Time At The X-ray		MTR	Total staff	Remarks
				Start	Complete		Start	Complete			
1	TU 6802	13	M	02:40	03:00	10 minute	03:02	03:07	20 Sec.	4	-----------
Total Time				20 MIN			300 Sec.				
2	W5 5083	14	M	11:38	12:01	10 minute	12:02	12:05	20 Sec.	4	-----------
Total Time				23 MIN			180 Sec.				
3	RJ 703	14	F	18:10	18:35	10 minute	18:37	18:43	20 Sec.	5	-----------
Total Time				25 MIN			360 Sec.				

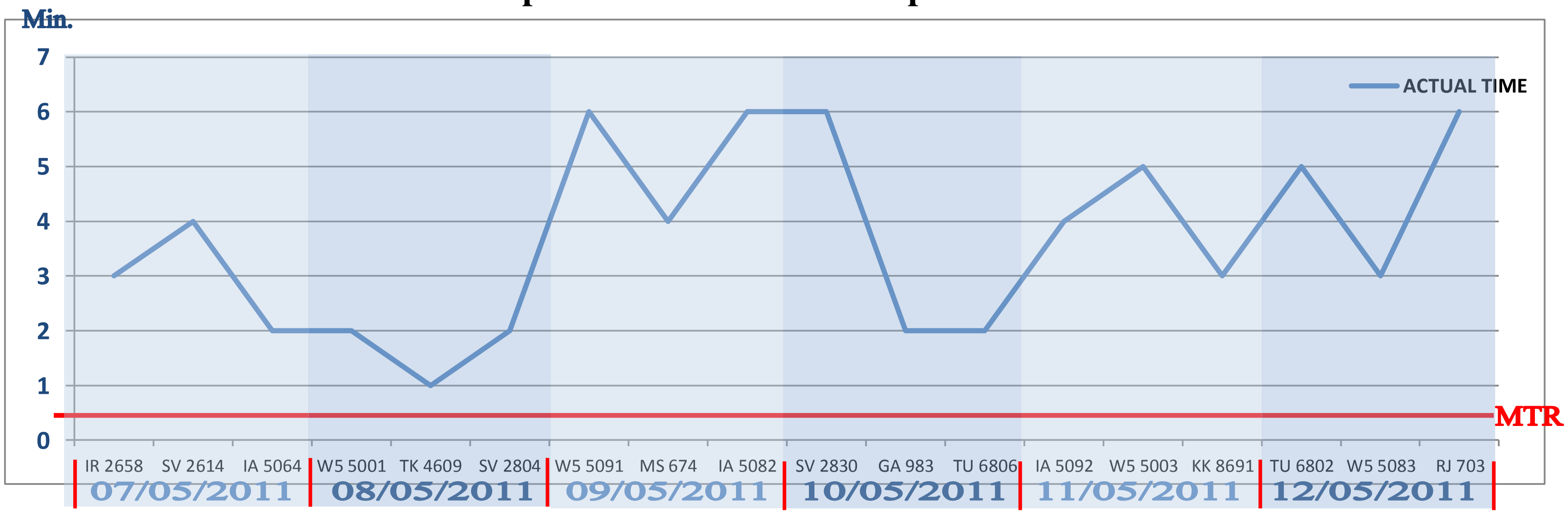
(Statistic Per Flight)

#	Flight #	Lounge	Total PAX	Actual Time For Queuing Until the X-ray		MTR	Actual Processing Time At The X-ray		MTR	Total staff	Remarks
				Start	Complete		Start	Complete			
1	TU 6802	13	280	02:40	05:17	Max 10 min. per passenger	03:00	05:28	20 Sec.	4	-----------
Total Time				03:17 Hrs.			02:28 Hrs.				
Average Time Per Passenger				42 Sec.			31.5 Sec.				
Total Time For All Flight				02:48 Hrs.							
2	W5 5083	14	430	11:38	13:08	Max 10 min. per passenger	12:00	13:14	20 Sec.	4	-----------
Total Time				02:10 Hrs.			01:14 Hrs.				
Average Time Per Passenger				18 Sec.			10.5 Sec.				
Total Time For All Flight				02:16 Hrs.							
3	RJ 703	14	168	18:10	19:19	Max 10 min. per passenger	18:07	19:23	20 Sec.	5	-----------
Total Time				01:09			01:16				
Average Time Per Passenger				24.5 Sec.			27 Sec.				
Total Time For All Flight				01:13 Hrs.							

Passengers Security Check (Analyzing per passenger)
For the Actual Queuing Time According to MTR
For the period from 07/05/2011 up to 12/05/2011



Passengers Security Check (Analyzing per passenger)
For the Actual processing Time According to MTR
For the period from 07/05/2011 up to 12/05/2011



General Comments of the Check in Area

- **GID:**

1- Staff shortages.

2- Sometimes late report of the staff due to shift change while passengers waiting in front of the lounge.

3- Sometimes the GID staffs have their meals while passengers waiting in front of the lounge.

4- Sometimes shortage of GID female staff.

With my best regard …

Motaz H. Mirah

Appendix C - Arena Sample Report

Actual model

Replications: 10 Time Units: Minutes

User Specified

Tally

Expression	Average	Half Width	Minimum Average	Maximum Average	Minimum Value	Maximum Value
Av real	29.1663	0.54	28.0303	30.2226	25.7576	34.8485
bhs	14.6717	0.00	14.6649	14.6754	12.0093	16.9857
f1 FlightsPerDay	35.0000	0.00	35.0000	35.0000	35.0000	35.0000
F2 PaxPerFlight	250.00	0.00	250.00	250.00	250.00	250.00
f3 img time	10.0000	0.00	10.0000	10.0000	10.0000	10.0000
f4 xray time	2.0000	0.00	2.0000	2.0000	2.0000	2.0000
f5 PercentAvImg	30.0000	0.00	30.0000	30.0000	30.0000	30.0000
health	0.6583	0.01	0.6386	0.6860	0.00	11.7891
img 1 time	42.4269	7.85	36.6174	72.7218	0.00	817.63
img 2 time	98.3943	5.38	80.6362	109.81	0.00	791.74
img 3 time	99.33	8.02	88.7843	126.41	0.00	726.53
img 4 time	40.2170	5.50	19.4797	46.9894	0.00	776.51
img time all	280.37	8.07	265.21	299.25	10.0000	817.63
immegration	280.37	8.07	265.21	299.25	10.0000	817.63
no disp count	2683.24	46.56	2572.22	2784.29	1.0000	6436.00
pax time	320.28	6.16	306.96	336.14	24.4369	850.54
Record passenger counter	4657.65	13.68	4614.22	4677.88	251.00	8785.00
xray	23.0907	3.49	9.8355	28.1838	2.0000	259.03

Counter

Appendix D – Maltlab PSO optimisation code

```
clear all
close all

%DATA

%Cap100%
A=-0.045; B=-0.058; C=-.314; D=-4.004; E=0.022; F=110.991;
XmatrixCap=[A B C D E];

%pax t
A2=.074; B2=.233; C2=1.032; D2=36.494; E2=-.129; F2=-14.985;
XmatrixPaxt=[A2 B2 C2 D2 E2];

%disp pax
A3=65.135; B3=12.465; C3=-342.068; D3=-308.797; E3=-5.203; F3=2791.414;
XmatrixDispPax=[A3 B3 C3 D3 E3];


N_par=5; %WAS =3
%PSO
N=100; % we need to justify why 20 particle--> see the paper
MaxValue=[300 300 10 10 100];
MinValue=[23 50 .1 .1 30];

% MaxValue=[1000 1000 1000 1000 100];
% MinValue=[1 1 1 1 1];

V=zeros(N,1);
for i=1:N
    Xp(i,:)=MinValue+(MaxValue-MinValue).*rand(1,N_par);
end;
%Second Part

PI=Inf(N,1);
PbestValue=Inf;
LbestValue=Inf;
V=zeros(N,N_par);
Xp_particleBest=zeros(N,N_par);

c1 = 1.49618;
c2 = 1.49618;
w = 0.7298;
Nit=2000;
for ii=1:Nit
    % for loop to the PI calculate per each Particle
    for i=1:N
        XB=(sum(2*XmatrixPaxt.*Xp(i,:))+F) /( .01*(sum(XmatrixCap.*Xp(i,:))+F2) + .↙
0001*(sum(XmatrixDispPax.*Xp(i,:))+F3) );
        PI_l(i,1)=20000-XB;
        %update the position value and the PI value per each particle
        if PI_l(i,1)<PI(i,1)
            PI(i,1)=PI_l(i,1);
            Xp_particleBest(i,:)=Xp(i,:);
        end
    end
```

```
    %update the L-best position value
    [LbestValuen,LbestIndexRow]=min(PI); %min_fitness, min_fitness_index
    if LbestValuen<LbestValue
        LbestValue=LbestValuen;
        L_best=repmat(Xp(LbestIndexRow,:),N,1);
    end
    %update the G-best position value
    [PbestValuen,PbestIndexRow]=min(PI); %min_fitness, min_fitness_index
    if PbestValuen<PbestValue
        PbestValue=PbestValuen;
        G_best=repmat(Xp(PbestIndexRow,:),N,1);
    end

    %PSO equation
    V=w*V+c1*rand(1)*(Xp_particleBest-Xp)+c2*rand(1)*(G_best-Xp); %update speed
    Xp=Xp+V; %update position
    % constrain Xp
    for i=1:N
        for j=1:N_par,
            if Xp(i,j)>MaxValue(j), Xp(i,j)=MaxValue(j); end;
            if Xp(i,j)<MinValue(j), Xp(i,j)=MinValue(j); end;
        end;
    end;
    PI_plot(ii)=mean(PI);
end

plot(PI_plot)
min(PI)
%paxt=20000-min(PI)
%paxt=XmatrixPaxt.*Xp(PI)+F
G_best(1,:)
```