Innovative Baggage Delivery Services in Future Air Transport Networks

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Abstract

Airports must accommodate ever increasing passenger numbers while offering a wide range of services. The services are provided through different facilities and processes creating a complex ecosystem of mutually dependent activities. Airport terminals are large-size multi-stakeholder buildings with innovative designs. The complex management of all airport operations requires proper recognition of all relationships among many stakeholders. The overarching aim of the management and design efforts so to provide high level of passenger satisfaction, and at the same time, to ensure smooth operations with minimum delays. The demands to accommodate increases in passenger numbers drive the need for expanding the capacity of airport and for using the resources and infrastructure more efficiently. The imbalance between the services demand and the available capacity creates congestion problems at different service points throughout the airport. Unlike many other previous works addressing mainly the airport capacity and congestion related to the number of aircraft and flights it is able to serve at any one time, our work is concerned with passenger services, and specifically with baggage delivery. More specifically, the concept of dissociating passenger travel from baggage delivery is introduced and evaluated from several different perspectives. The baggage dissociation can help to improve the passenger air travel experience, make public transport to airport more viable option, and thus, reduce ground-side congestion at airports with reduced CO2 emissions, use existing airport capacity more efficiently while reducing footprint of new airports, optimize monetization of cargo and baggage delivery, elevate the value of non-hub airports, and exploit the new aircraft designs to name a few. It can be argued that innovations in baggage delivery will be mandatory in order to meet the future passenger demands. However, despite these significant drivers, at present, there are still many regulatory and infrastructure challenges which have to be overcome before baggage dissociation can become reality. This thesis contributes several studies towards feasibility of the baggage dissociation, two ways have been presented to pave the way for the baggage dissociation the new baggage delivery networks and the Satellite terminals (Off-Airport terminals)

Declarations

This work has not previously been accepted in substance for any degree and is not being concurrently submitted in candidature for any degree.

Signed.................. [redacted] ....

Date.................................1/1/2020..

This thesis is the result of my own investigations, except where otherwise stated. Other sources are acknowledged by footnotes giving explicit references. A bibliography is appended.

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CHAPTER 6

SATELLITE PASSENGER TERMINALS

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List Of Publications By Candidate

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Conference Papers

International Conference on Air Transport

1. Al-Hilfi, S., & Loskot, P. (2016). Arrival And Departure Flight Statistics For The Largest Airport Hubs.

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2. Al-Hilfi, S., & Loskot, P. (2017). Growing The Congested Airports: Satellite Passenger Terminals.

Papers Submitted To Journals

Elsevier Journal of Air Transport Management

1. Al-Hilfi, S., Yu, H. & Loskot, P. (2019). Design Of Baggage Distribution Networks For Future Air Travel.

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ABBREVIATIONS

Eurocontrol	The European Organization for the Safety of Air Navigation, It is an international organization that works to achieve safe and seamless air traffic management across Europe.
FAA	The Federal Aviation Administration, it is a governmental body with powers that regulate all aspects of civil aviation in in United States and the surrounding international waters.
IATA	The International Air Transport Association, it is a the trade association for the world's airlines, it supports the airlines activities and helps formulating the industry policy and standards.
ICAO	The International Civil Aviation Organization, it changes the techniques and principles of the international air navigation and fosters the development and planning of the international air transport to ensure orderly and safe growth.
ATC	Air Traffic Control.
ATM	Air Traffic Management.
BRS	Baggage Reconciliation System.
CAA	Civil Aviation Authority.
CSV	Comma-Separated Values.
TOA	Time of Arrival.
TOD	Time of Departure.
UTC	Coordinated Universal Time.
ETA	Estimated Time of Arrival.
ETD	Estimated Time of Departure.
ICT	Information and Communication Technologies.
KPI	Key Performance Indicator.
MLW	Maximum Landing Weight.
MTOF	Maximum Take-off Weight.
MZFW	Maximum Zero-Fuel Weight.
OEW	Operational Empty Weight.
PNR	Passenger Name Record.
XML	Extensible Markup Language.
MCLP	Maximal Coverage Location Problem.
BSCs	Baggage Sorting Centers.
BDCs	Baggage Distrbution Centers.
BHS	Baggage Handling System.
CDM	Collaborative Decision Making.
RPK	Revenue Passenger Kilometers.
OAT	Off-Airport Terminal

CHAPTER 1

INTRODUCTION

1.1 BACKGROUND

Airports are required to accommodate a huge range of allied facilities and operations in which the performance of any one process can influence the other. Airport terminals consist of large-scale, multi-stakeholder buildings that require innovative design and management approaches to manage a large number of interacting stakeholders and services [1].

Airport design and operations management require a proper recognition of the relationship between all interdependent activities to achieve a high level of passenger satisfaction and at the same time to ensure smooth operations at the airport. According to statistics, the aviation industry has grown rapidly for both leisure and business purposes. This noticeable growth in air transport has increased the need for providing more-efficient airport services that can accommodate this continued growth in demand. However, most of the major airports worldwide experience problems adapting to this growth because of the imbalance between the available capacity and demand, and this eventually leads to congestion problems.

In an attempt to manage airport congestion, many researchers have focused on analyzing the effects of airspace and runway parameters and their contribution to creating the congestion problem. However, not much emphasis has been given to analyzing the contribution of the ground-side of the airport to solving this problem. The purpose of this project is to introduce a baggage dissociation concept as a proposed solution that can help with congestion problems at the airports. Due to the complexity of the implementation of regulation and infrastructure reasons, the current research primarily investigates the main challenges as well as the main drivers. In addition, it intends to carry out an initial evaluation into the feasibility of passenger/baggage dissociation.

Considerable studies are available in the literature that deals with the congestion problem at airports and the solutions that have been presented are explained in section 2.7.

The previous research related to airport congestion were primarily aimed at reducing the ratio of demand/capacity. However, no attention has been given to highlighting the importance of passengers/baggage dissociation. The concept of the complete passenger/ baggage dissociation is a relatively new initiative, and very limited data sources are available to investigate the complete implementation of this concept, therefore for the proposed solutions the location problems have been examined only for both the Baggage Sorting Centers (BSCs) in Greater London and the Satellite terminals [Off-Airport Terminals] in the United Kingdom.

1.2 RESEARCH AIMS AND OBJECTIVES

The primary objective of this research is to deliver the idea of baggage / passenger dissociation as a solution for the airport congestion problem. Also, it aims to find the methods that enable the implementation of this concept through presenting the idea of new innovative baggage delivery network and the Satellite terminals (OAT) . Hence, to achieve these objectives, the following questions require appropriate answers:

1. How can the complete passengers/ baggage dissociation concept incorporated in to solving the congestion problem.

The first research question addresses the main objective of this research, whilst appropriate answers to the following three questions will allow achieving our goal through various qualitative analysis techniques.

2. How to utilize air transport data to implement the dissociation concept ?

3. Can the complete passengers / baggage dissociation concept be beneficial to airlines or not ?

4. What are the possible ways to implement this concept ?

These research questions will serve as guidelines for the research approach to seeking the possibility and the benefits of applying this innovative concept. Answers to the first and second research questions are sought through comprehensive investigation of a set of one week's data for more that 70 large hub airports in June 2016. For the third research question some preliminary results have been collected from a set of the 12 most popular aircrafts to investigate whether this service is profitable for airlines or not. Finally, two ways have been presented to implement this concept either through adapting new baggage distribution networks or using Satellite terminals (OATs).

1.3 THE BAGGAGE DISSOCIATION CONCEPT

Baggage dissociation can be considered in a broad sense or in a strict sense. Baggage dissociation in broad sense is concerned with the ground segment only. Specifically, luggage is collected at passenger premises by a 3rd party courier service company, delivered to the airport and then checked in on behalf of the passenger. The passenger can then undertake a hassle-free trip to the airport. A major challenge of this service is how to prevent unauthorized tampering with the baggage contents. However, this issue is now partly mitigated by the widespread X-ray screening of the checked- in baggage at all major airports as a part of the check in process. Upon arrival to the destination airport, a similar baggage home delivery services can be requested by some passengers. Strict airline rules about the baggage contents security are now avoided, however, the challenge is the customs inspection when the reconciliation of the passenger and their luggage occurs outside the airport, for example, at the hotel. More importantly, in both cases, passengers and their luggage travel on the same flight, even if the journey consists of multiple legs and is operated by different airlines.

Strict sense baggage dissociation aims to deliver baggage independently from the passenger travel including the air segment. The key challenge here is the violation of the current IATA General Conditions of Carriage for passengers and baggage Article 9 / Section 9.4.3 which states "*Checked baggage will be carried on the same aircraft as the passenger unless Carrier decides that this is impracticable, in which case Carrier will carry the checked baggage on Carrier's next flight on which space is available*". However, the solution to this issue can be done by improving the baggage screening sensitivity to provide safety and to guarantee the security of the baggage contents , or to have dedicated flights delivering baggage only with no passengers on board.

Baggage dissociation can be considered in several travel scenarios and contexts. It can be between the destination airport and the journey endpoint, such as a hotel, which is probably the most straightforward since it involves minimum security and regulatory restrictions. Companies providing this service already exist in large cities hosting major airports..

The baggage dissociation between the point of origin, such as home, and the departing airport has to implement a secure baggage delivery to the airport. The airport drop-off may or may not require the presence of the passenger. In the latter case, the service provider must gain acceptance from the airlines to satisfy the minimum security standards. This service is encouraged by some airlines by providing advanced baggage check in at the airports.

The complete end-to-end baggage dissociation is envisioned as the travel of the future. It is a paradigm shift which is going to affect the air travel . Such a baggage service resembles a parcel delivery service, so bags could be treated as parcels and sent completely independently of the passenger traveling, this point is discussed in detail in Chapter Five. This idea is well aligned with the vision of the Physical Internet [2].

Unlike highly regulated delivery in air transport, the surface baggage delivery to and from the airports is currently unregulated. It creates liability and security problems for 3rd party baggage couriers. It is likely that adopting some international regulations for the baggage delivery via multi-modal transport would stimulate this segment of industry [3].

The implementation of baggage dissociation is likely to be realized in several phases which are still subject to much research. One possibility is to exploit a number of baggage drop-off and collection points or auxiliary terminals throughout the city. Currently, there is no public market research indicating prospective adoption of the new baggage services by travelers. Particularly business travelers may be concerned if they are unable to access their bags immediately upon arrival to the destination airport. Moreover, delivering baggage dissociated from passengers requires careful and complex planning well ahead of the travel.

1.4 RESEARCH SIGNIFICANCE

This research provides a significant contribution towards proposing the complete passengers / baggage dissociation in both ground and air segments. Also, it proposes two ways to implement this concept: new design of baggage networks or using Satellite terminals (OATs). The dissociation concept has been used in some large hubs as an extra service and in the ground segment only and the baggage still travels with passengers on the same aircraft. However, no specific efforts are made in the available literature that propose or investigate the complete passengers / baggage dissociation and this research is the first of its kind that offers a rational integration of a number of existing fields of knowledge to be incorporated in new baggage delivery networks or Satellite terminals (OATs) .

Following are the three major contributions to the current field of knowledge:

- A complete passengers / baggage dissociation concept is proposed: highlighting its main challenges and main drivers.
- The envisioned network for baggage delivery, new baggage delivery network that is inspired from the current parcel deliver network to delivering baggage to its final destination.
- Satellite terminals (OATs), New models of passenger and baggage processing that can improve the airport performance by off-loading many services outside the main airport terminals.

Overall, the research outcomes provide a new perspective in the field, since the proposed concept can help to mitigate the congestion problem at the same time it well also improve the passengers' experience.

1.5 RESEARCH METHODOLOGY

Figure 1.1 presents a flowchart of the overall research methodology and this is thoroughly explained in Chapters 3 to 6. The first phase focuses on describing the context in which the congestion problem occurs and identifies the main two concepts: demands and airport capacity. This theoretical knowledge enables us to understand the purpose of the research objectives. The second phase is based on explicit problem identification, two mathematical models have been formulated, one to show how air transport data can be used to implement the proposed solution and the other to calculate the profits that can be achieved by adopting the proposed solution. The last phase of the methodology, as represented in Figure 1.1, consists of building the mathematical model that is required to find the best location for both Baggage Sorting Centers and the Off-Airport terminals. All this has been done through various calculations that are used to elucidate insights into the structure and operations of the airline networks which performed in Chapter 3. A premium investigation of the baggage fees and baggage revenue is presented in Chapter 4. The design of the envisioned Baggage Ground Distribution Networks is discussed in Chapter 5, as well as investigating the possibility of distributing innovative baggage sorting centers through the Greater London area. Extraction of useful information that relates to the main functions of the airport terminal and having a clear idea about the terminal operations, its facilities and passenger processing is presented in Chapter 6. In addition, the Concept of Off-Airport terminals, including the outline of the main services and the advantages behind adapting these terminals are also presented in this chapter too.

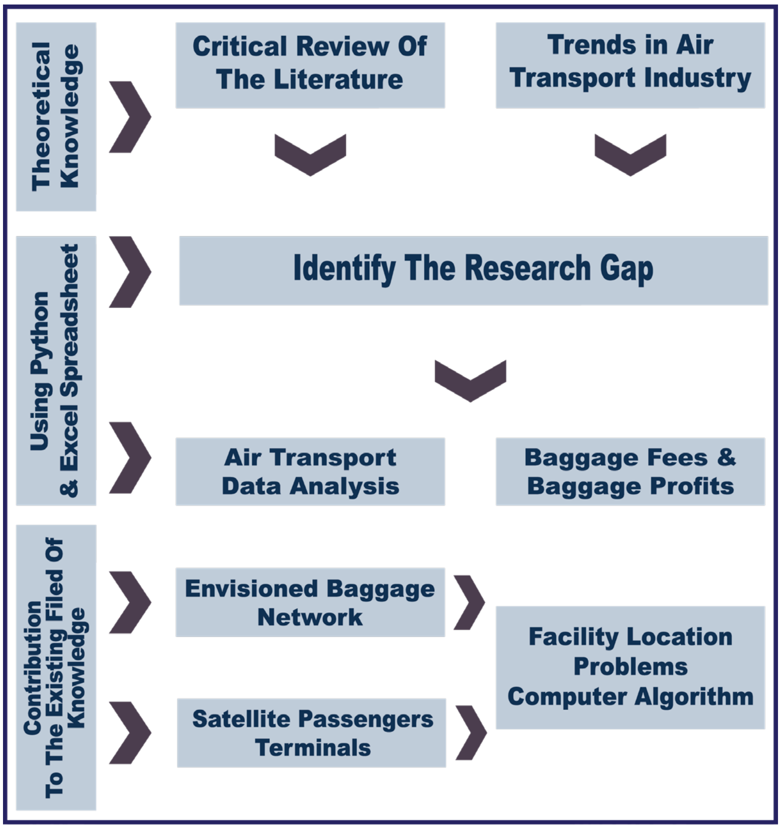

Figure 1.1 Overview of the research Methodology.

1.6 OUTLINE OF THE THESIS

The outline of the research activities that have been carried out as a part of this project are briefly discussed in the following paragraphs.

- Chapter 2: Review of the relevant literature considered as one of the significant aspects of any research project since it helps to investigate the current state-of-the-art and at the same time it is useful to identify gaps in research. A comprehensive review of the relevant literature has been presented in this chapter in which four groups of solutions are discussed after providing a full understand of the serious problem that many hub airports worldwide face today.

- Chapter 3: Presents the elements and issues that related to air transport data and it discusses the definition of the Passengers Experience concept, to explain the relationships between passengers satisfaction and the air transport business. In addition, a significant number of results are presented to show how small sets of air transport data can be valuable.

- Chapter 4: Discusses whether the baggage / passenger dissociation solution is beneficial or not. Depending on the payload-range diagram, the performance of 12 aircraft are analysed to evaluate if this concept can make revenue for the airlines.

- Chapter 5: Argues that the complete end-to-end dissociation involving the air segment is critically dependent on the dissociation in the ground segment. Therefore, as a prime research objective and inspired by the exciting parcel delivery networks, the envisioned network for baggage delivery is considered here.

- Chapter 6: A new concept Satellite terminals (OATs) is proposed. The development of this concept is implemented through understanding the airport terminal design processes, the main functions of the airport terminal, how off-loading some passengers processing functions outside the airport affects the airport performance . It also, investigate what are the advantages behind adapting this concept as well as investigating the location issues.

- Chapter 7: The results and contributions presented in the thesis are evaluated. Implementation strategies of the proposed concepts i.e. baggage dissociation and Satellite terminals (OATs) are outlined. In addition, possible future research directions are discussed.

Chapter 2

Current Trends In Air Transport

2.1 INTRODUCTION

Congestion and capacity issues are discussed as the two main focus areas in the current air transport research to provide a full understanding about the serious issue that many hub airports worldwide are facing today. Background information of the Air Transport trends is also presented. Finally , the relevant literature has been collected and form it four strategies to deal with the congestion problem have been identified.

2.2 DEMANDS FOR AIR TRAVEL

Air transportation is the fastest growing sector of transportation in the developed world. The passenger aviation market is constantly increasing in terms of the number of passengers per year as outlined in Figure 2.1. This increase in demand puts significant pressures on both airports and airspace resources as they are not expanding at the same rate. This growth in demand, which is more than the system capabilities, can cause congestion problems and generate delays at major airports worldwide. The Air Transport Action Group (ATAG), has acknowledged that airport infrastructure constraints generate major delays, which have serious economic costs that must be taken into consideration. Airport terminals play a key role in the commercial aviation system sometimes fail to accommodate this growth due to inefficient operation or lack of capacity. It is a challenging task for airport planners, operators and developers to keep pace with this rapidly growing demand [4]. Therefore, airlines and the airports are required to intensify their effort to improve their services to retain their customers for future flying purposes (customer loyalty).

Moreover, it is significant for both airlines and airports to focus on the service quality that makes a lasting impact on passengers. A long-term plan that prioritizes passenger satisfaction arguably can be said to be a valuable and a long-term strategy. Increasing demand for air travel is a major challenge of the air transport's future. These demands could be for leisure, business or freight. The International Air Transport Association (IATA) announced that the global passenger traffic results for 2018 showed demand rising by 6.5% for the whole year compared to full-year 2017 [5]. In addition, passenger demand has been boosted because of many reasons such as low airfares that result from increasing competition between airlines, air transport deregulation, combining with less cost and more efficient aircraft technologies. According to the European Commission, the air transportation sector is expected to increase its modal share by around 5 %, specifically from 8% in 2010 to 13% in 2050, making this mode second most popular after road transportation [6]. Growing the availability of affordable air travel has changed the aviation industry from a luxury industry that served a target group to an essential transportation mode that has created new potential for both trade and tourism over the world. Therefore, it is obvious that the growth of air transport will be certain in the near future. Figure 2.1 represents the tenfold expansion of air travel volume during the last 40 years as has been measured by the worldwide scheduled Revenue Passengers Kilometers (RPKs). This expansion is three times greater than the growth of the world's economies and at the same time, it reflects the high-income elasticity of air travel, in which air travel has been one of the fastest growing economic sectors [7].

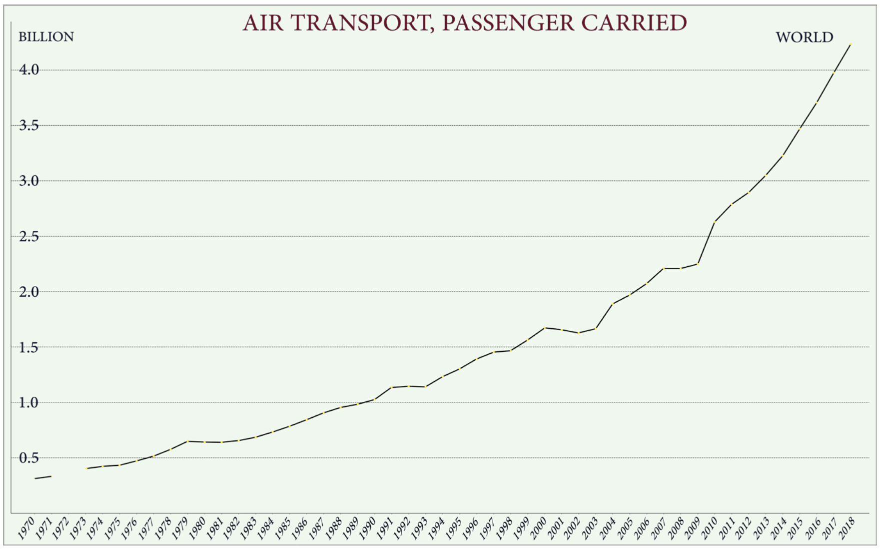

Figure 2.1 Air Travel Has Expanded Tenfold In The Past 40 Years [8].

However, such growth is hard to predict for different causes, such as airport capacity limitations and congestion, fluctuating oil prices and the concerns of the global climate and customer demands. For these reasons, air transport is considered to be one of the most complex industries, that is facing the problem of growth creation. Moreover, the air transport industry is now facing many challenges that result from that growth and the term "sustainability" is the subject of many debates.

The trouble-free flow of customers results in the perceptions amongst certain consumers of a reduction in the quality of service. Therefore, it is time again to analyze the passengers' needs, in particularly after the wake-up call that aviation and other transport modes received in September 2001. Passengers request efficient, fast and in many cases, environmentally friendly transport connections. Considering the recent situation in aviation, these requirements are very hard to fulfill, due to rising delays and congested airspace and airports. Airport congestion is a growing problem, and it is a limiting factor at the same time. Many international hubs and major airports are operating at their maximum throughout for long periods of the day, while some have already reached their operating limit constraints. This situation is expected to become more common as traffic continues to increase. Furthermore, the future distribution patterns of traffic are most likely to generate congestion at these airports which are currently do not experience capacity problems.

2.3 AIR TRANSPORT STATISTICS

Globally, air transportation is expected to maintain positive growth rates up to 2030, in spite of the challenges faced by the industry as shown in Figure (2.2). Airline companies are struggling with both sluggish economic growth and high jet fuel prices. However, these difficulties are expected to be offset by an increase in passenger numbers, which, in turn, is projected to improve the financial performance of the airline sector. According to IATA, in 2018 the global aviation industry attained up to 38.4 billion US dollars in profits [9], while it was only 8.3 billion US dollars in 2011. Between 2017 and 2036, the number of passengers is predicted to grow at a compound annual growth rate of 4.7%. Low-cost carriers and regional airlines both revolutionized the airline business by presenting innovative low-fare business models. Aviation demand is supposed to be fueled by the rising flow of the middle classes in emerging markets. Therefore, the air traffic industry is predicted to grow most significantly in Africa and Latin America. In 2017, the airports in Beijing (IATA: PEK), Atlanta (IATA: ATL) and Dubai (IATA: DXB) were ranked as the 3 major airports for passengers traffic [8].

According to ICAO and IATA statistics, in 2017 the RPKs has risen to 8% compared to 2106 as depicted in Figure 2.2. In other words, around 4.1 billion passengers were carried on scheduled services by the aviation industry .

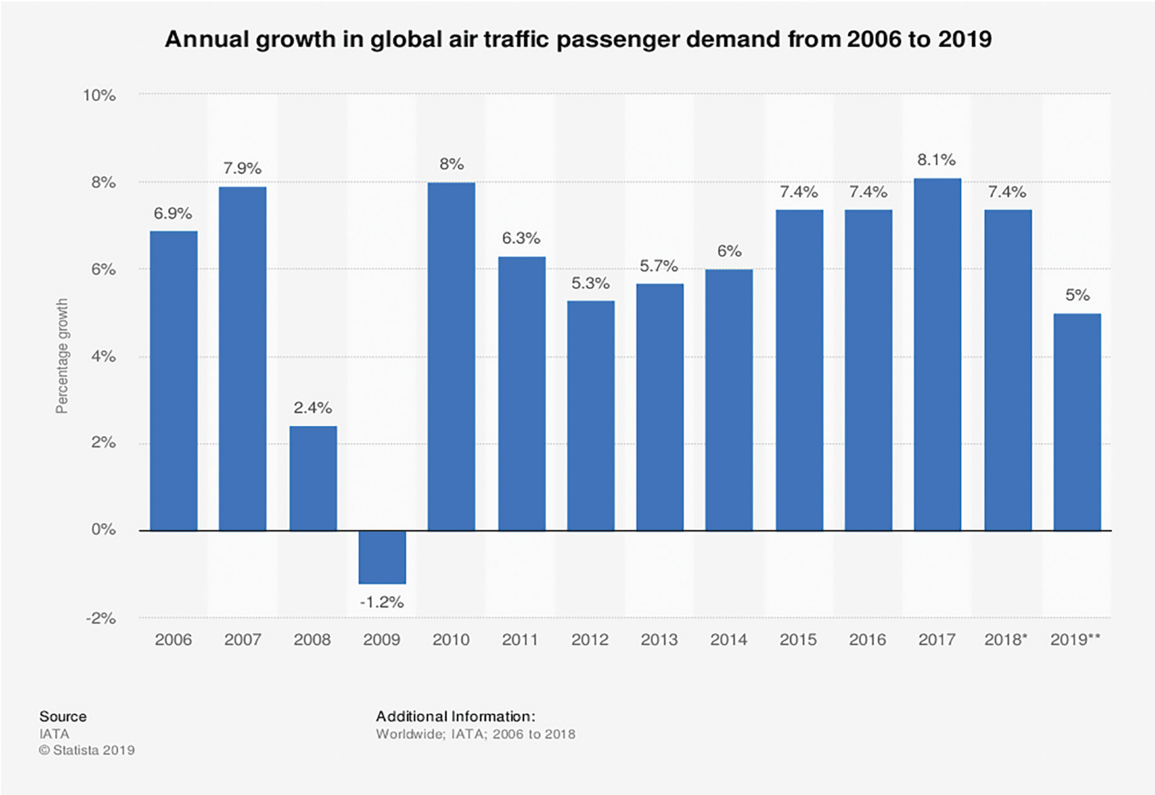

Figure 2.2 Annual Growth in Global Air Traffic Passenger Demand Source IATA[8]

In fact, all regions in the world recorded higher growth rather than the previous years, except for a slowdown in the Middle East. This slowdown is due to a number of factors: such as the competitive environment, competing hubs and more point-to-point services, low oil prices and the impact of a strong US dollar. The region carried a 14% RPK share and experienced a significant decline in growth from 11.8% observed in 2016 to 6.9% in 2017. Europe remained the largest international market with a 37% share of the world international RPKs, and grew strongly by 8.1%, supported by improved economic conditions in the region. Asia/Pacific had the second largest share with 29%, and grew by 9.6%, the second strongest growth among all regions. North America accounted for a 13% share, and demonstrated an improvement compared to 2016, however, remained as the slowest growing region with a growth of 4.9%. Carriers in Latin America and the Caribbean managed 4% of world international RPKs and saw the biggest improvement among all regions and recorded the strongest growth at 10.0%. Africa had the smallest share of 3% [7].

2.4 AIRPORT CONGESTION

Generally, congestion occurs when demand for infrastructure exceeds the available capacity. One of the main effects of this phenomenon is flight delay. The lack of sufficient airport capacity that is required to meet the demand caused by passengers and aircraft movements. The consequent problem is generated as a result of saturated airports and the delay of the operations and has become a common challenge at major airports in the world, thus affecting the mobility of both people and cargo [10].

In air transportation, door-to-door travel time is divided into three parts: the travel time to and from the airport, then the time that is required at the passenger terminal before and after the departure, and finally the air-side travel time once boarded [11]. Demand refers to the number of the scheduled flights that arrive or depart at a given time period (the rate of the arrival or departure flights). Capacity can be defined as the maximum number of the arriving or departing flights that can be handled at a given period of time. One of the main direct results of the capacity-demand imbalance is airport congestion and flight delay. Most of the major airports worldwide experience this significant problem. Some of the busiest European airports currently operate at full capacity, while in the U.S. around 25 airports are severely congested. Unfortunately, airport congestion is a global trend, with the continuous increasing demands for air transportation, congestion and delays at airports have become more and more usual. Flight delays, especially at the hub airports have a multitude of effects, since they propagate further into the airport network. In addition to the operational bottlenecks and passenger dissatisfaction, congestion and delays also have serious environmental and economic impacts that spread over the whole air transportation system.

In the European Union, Air Traffic Management (ATM) inefficiencies led to 10.8 million minutes of flight delays in 2012, which produced 7.8 million tones of wasted CO2 and cost 4.5 billion Euro to airspace users and 6.7 billion Euro to the passengers[12]. In addition, EUROCONTROL performed an analysis in 2013, which indicated that in 2012 there were only six airports that were congested, in the sense they were operating at 80% or more of the available capacity for more than three hours per day. In the most-likely scenario of the 2035 forecast, this climbed to more than 30 airports. In Europe, one of the worst transportation problems is congestion. It costs Europe around 1% of its GDP annually and at the same time causes heavy amounts of It costs Europe around 1% of its GDP annually and at the same time causes heavy amounts of carbon and other unwelcome emissions [10] . According to the Aviation Council International in 2017, consumers in Europe were paying EUR 2.1 billion annually in additional air fares, due to the capacity constraints at airports [13]. Congestion problems at airports can occur due to different reasons, that can be related to the airports themselves, to the airline schedules, or to the travel agencies and passengers.

2.5 CONGESTION REASONS

Airports face many problems which may be commercial, political, economic and/or regulatory in nature. These problems can have a significant impact on the long-term strategies and master plans of each individual airport. Hence, the airport responsible authorities have to deal with these problems. For example, theoretically, there are adequate airports and runways in Europe. However, market forces and other politics and environmental factors dictate the pattern of traffic. This matter means major airports are becoming, or continuing to be, congested, resulting in difficulties and frustration for both aircraft operators and passengers. It is presumed that these factors create additional limitations for airport expansion. However, if these factors are addressed early and properly, they will not become a limiting factor anymore and they will allow sustainability. One of the main causes of congestion in the air transport industry, is that the growth in demand has not been met with an equal growth in available infrastructure. The other major contributor to the congestion problem is that airlines are operating in a deregulated and competitive market. This is mostly the means of operation for the Hub and Spoke networks, in which emphasis on high frequency as a competitive element, is the matter that results in using smaller aircrafts. Also, traffic variability means departures are not evenly distributed over the year or even on the same day, which can cause peak loads, if the terminal resources are not managed efficiently. For example, during holidays these peak loads can result in long queues at the check-in desks at terminals [14].

Moreover, airport congestion can be caused due to political reasons. When suggestions indicate that the spare capacity in one airport could solve the lack of the other, there is clearly a relationship between the two when states take action that effectively direct traffic and deform the normal function of the air transport market. In fact, this kind of negation agreement can result in making regional airports deprived of the air service, while these airports may already fight hard to persuade a third country airline to fly. However, and whatever is the reason, such intervention by governments can trigger congestion at hub airports.

Growing congestion and delays in air transportation systems are serious threats that can affect the entire economy. A study conducted was in 2015 to examine the trends from the most constrained airports: London Heathrow Airport, Beijing Capital International Airport and Haneda Airport in Tokyo, the main finding was when the airport approached its maximum capacity, the passenger growth stalled. For example, the number of travelers through Heathrow has grown at less than 1%, on an average annually since 2000 while during that time the other airports in London grew at nearly 2%. Moreover, the most surprising result was the way Heathrow's limitations affect the neighboring airports. The logical assumption is those passengers who have been squeezed out of Heathrow, turned to the nearby airports. While in fact other London airports (City, Gatwick, Luton and Stansted) captured only around half of Heathrow's overflow. Moreover, what happens in reality are those transit passengers travel to their destinations using other intercontinental hubs such as Frankfurt and Amsterdam. As a result, airport congestion pushes the potential passengers to fly to or through different airports. Furthermore, the impact of congestion can go even further, the 2013 UK Airports Commission report suggested that failing to alleviate capacity constraints at the nation's airports, could cost users and providers of airport infrastructure up to £20 billion over the next 60 years, and then which may cost the economy up to £45 billion [15].

2.6 AIRPORT CAPACITY

Generally, Capacity refers to the airport ability to handle a given volume of demand (traffic). In other words, it is the limit that cannot be exceeded without causing an operational penalty. When airport demand approaches this limit, queues of users begin to develop, and in this case, they experience delay. Mostly, high demand in relation to capacity means longer queues and greater delays. Airport capacity has been defined according to the U.S. Congress, Office of Technology Assessment as [16]:

"The number of air operations, landings and takeoffs, that the airport and the supporting air traffic control (ATC) system can accommodate in a unit of time, such as an hour."

Also, it has been mentioned that capacity is not a single number, but it is dependent on various factors, both land-side and air-side. The land-side capacity can be determined by the number of passengers that the airport terminal can accommodate. For example, the size and number of lounges available at the airport, and the capability of the baggage-handling equipment. The other important part of the airport's land-side capacity is the ground access, which means adequate roadways, transit connections, and passenger parking spaces. While the air-side capacity can be defined as the maximum service rate that relies on the physical and the operational characteristic of both the runway and the aircraft type.

A memo from the European commission has mentioned that there are several limitations to capacity [17]. Among these, there are insufficient ground handling and noise restrictions. Also, they noted that the demand for air traffic keeps increasing, and it will be nearly double in Europe by 2030. The memo indicated that five large European airports, Düsseldorf, Frankfurt, London Heathrow, London Gatwick and Milan Linate, have already reached their maximum capacity. Further, by 2030 there would be more than nineteen airports operating at their capacity limit as well.

Table 2.1 shows the sample of five European airports. It is clear that there is a problem with lacking capacity and this problem will escalate during the next years.

Table 2.1 Forecast Of Airport Congestion And Capacity Demand For Five Large European Airports. c.f. European Union, 1995-2017

Airport	2010	2017	2025	Capacity Assumptions
London Heathrow	Demand exceeds capacity most or all day	Demand exceeds capacity most or all day	Demand exceeds capacity most or all day	Assumes no third runway, or mixed mode, or relaxation of annual movement cap.
London Gatwick	Demand exceeds capacity most or all day	Demand exceeds capacity most or all day	Demand exceeds capacity most or all day	Assumes no new runway but increase of 2-3 movements / hour on current runway
Düsseldorf	Demand exceeds capacity most or all day	Demand exceeds capacity most or all day	Demand exceeds capacity most or all day	Assumed 10% increase in capacity in 2015 but no further increase
Frankfurt	Demand exceeds capacity most or all day	Sufficient capacity most or all day	Demand exceeds capacity during part of day	New runway (2011) and terminal (2015) that allow increase from 83-126 movement/hour
Milan Linate	Demand exceeds capacity most or all day	Demand exceeds capacity most or all day	Demand exceeds capacity most or all day	Assumes no amendment to consider

The same memo showed that six of eight sample airports will have an increased number of hours per day, where the demand exceeds the capacity as clarified in Table 2.2 For example, London Gatwick has14 hours per day while demand exceeds the available capacity and the number of hours will increase to 17 in 2025.

Table 2.2 Hours Per Day Where Demand Exceeds Capacity.

Airport	2010	2012	2017	2025
Dublin	1	3	0	0
London Gatwick	14	14	14	17
London Heathrow	15*	15*	15*	15*
Madrid Barajas	6	12	6	12
Paris CDG	8	11	12	15
Palma de Mallorca	2	2	2	3
Rome Flumicino	5	6	6	9
Vienna	5	5	9	5

* *Very limited capacity available in some off-peak hours*.

In fact the common challenge at many the major airports in the world is the lack of sufficient capacity that results in delay and congestion problems.

2.7 LITERATURE REVIEW

Airport congestion is the subject of many studies in the field. Different methodologies have been used to assign possible solutions for this problem. However, all of these solutions focus on finding ways to reduce the ratio of demand/capacity that can be achieved by increasing the capacity, reducing the demand, or combining both options. Generally, these solutions can be categorized into four groups as shown in Figure 2.3.

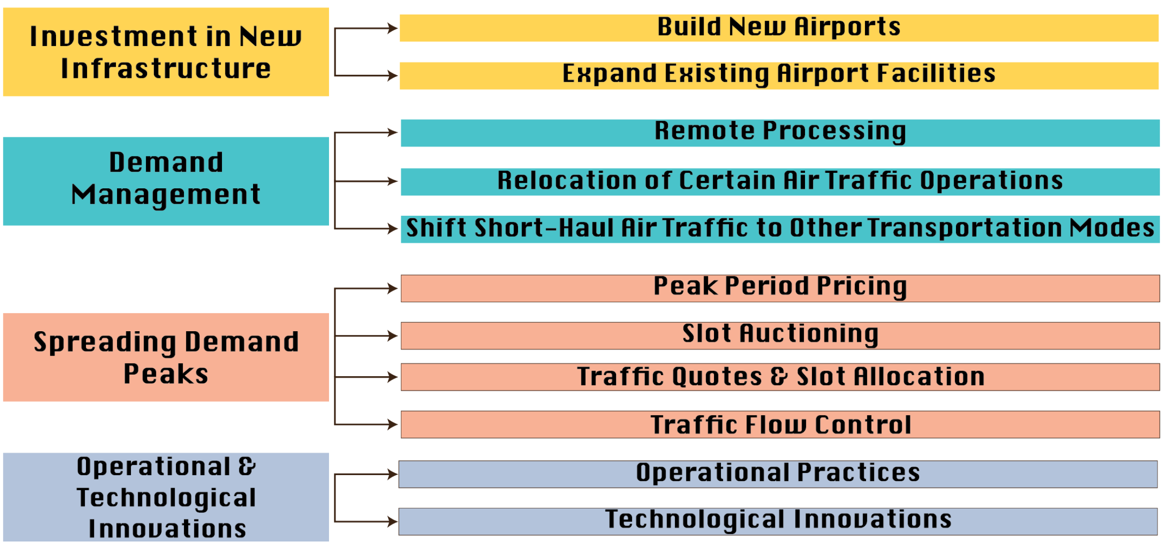

Figure 2.3 Options for Balancing Airport Capacity and Demand to Solve Congestion Problem

2.7.1 METHOLODOLOGIES TO SOLVE THE CONGESTION PROBLEM

2.7.1.1 GROUP 1: INVESTMENT IN NEW INFRASTRUCTURE

The first one is the long-term solutions that include building new airports to increase the system capacity. These types of solution are difficult for many reasons such as funding constraints, environmental concerns and opposition by local communities to the idea of developing new airports. Also, such developments cannot address the need for new capacity in the short term. For example, constructing a new terminal, usually requires between five and ten years to be completed. Medium-term approaches would consider expansion of existing airport facilities is rendered highly unlikely for strongly interrelated reasons associated with large capital expenditures , environmental impact, land availability, lengthy approval processes, and political feasibility [18]. Moreover, even intuitively airport expansion relieves the capacity constraint to some extent and is expected to reduce the air traffic congestion but in reality not always runs as expected. As an example, Heathrow airport, had no patent improvement in the average flight delay can be found following the capacity jumps except in the year 2008.In contrast, the average flight delay and total number of available seats exhibited a similar trend most of the time. This shows that the effect of airport expansion on the level of service of the airport and airlines is questionable. According to the economic analyses of Lambert–St. Louis International Airport that were implemented by Cohen and Coughlin in 2003, expanding the capacity of airports may reduce the congestion, but they also showed that congestion may still persist. Moreover, they stated that airport expansions frequently disrupt neighborhoods and nearby communities, an example of which is the destruction of homes in Bridgeton that was judged to be a necessary part of the Lambert expansion. Homeowners received compensation for their property, but entire neighborhoods were destroyed. Another disruption is the additional noise imposed on surrounding communities due to larger airports [19].

2.7.1.2 GROUP 2: DEMAND MANAGEMENT

The reduction of demand at an airport can be achieved by:

A. Shifting a portion of demand to alternate locations or other modes of transportation. For instance:

1. Remote processing: This proposal helps to reduce the demand in the airport facilities by servicing part of it at alternate or complementary locations outside the airport. In terms of the airport land-side, this would apply mainly to the parking of vehicles, passenger processing and the allocation of aircraft gates.

2. Parking of vehicles outside the airport: When the capacity of the airport car parking facilities is insufficient to meet demand and cannot be expanded efficiently within the limits of the airport, additional parking facilities could be constructed outside the airport and connected to the terminal through a circulation system, for instance, using shuttle buses.

3. Processing of passengers outside the airport: This involves primarily the delivery of boarding passes and activities related to verification of baggage at a remote location, or at key locations within the city, where the sources and destinations of passengers are concentrated. It also includes the transport of passengers to the airport to complete the remaining activities related to the flight.

4. Remote positions for aircraft: Lack of sufficient positions for passenger embarking/disembarking may be compensated by the use of specialized vehicles to transport the passengers between the terminal building and their aircraft in a remote position [20].

Unfortunately, not many authors have investigated these solutions. However, Zundert (2010) stated that many of the proposed solutions to relieve the congestion problem in the literature, have been focused on changes inside the airport terminal. While he investigated the off-airport baggage check-in as a service for passengers to handover their baggage to the airlines based on the most suitable location for them. This investigation was only for

Amsterdam Airport Schiphol and KLM Royal Dutch Airlines [21].

B. Relocation of certain air traffic operations

1. Commercial operations: This proposal is based on a policy decision by the authority to relocate some segments of the commercial traffic operation (for instance international flights or charter operations), or certain airlines to other less-utilized or less-congested neighbouring airports. This policy could be established by giving incentives to the airlines or may be forced through actions to relocate their operations.

2. General aviation: One method to maximize the use of available capacity at a busy airport is to restrict its use to non-commercial flights, such as general aviation operations.

C. Shift short-haul air traffic to other transportation modes

Replacement of short-haul (up to 500 km distances) flights with other transportation modes may release some degree of congestion at airports with high proportions of such traffic. An alternate mode could be high-speed surface transport link, for instance, a train. However, full complementarity will depend on strong integration of the modes through schedule coordination, inter-modal baggage transfer, compatible ticketing procedures and technologies and so forth.

Additionally, less congested secondary airports that serve the same catchment areas as the primary airport(s) in many large cities could absorb sizable shares of existing traffic and accommodate future growth given requisite upgrading of facilities (e.g., construction of new terminals and lengthening of runways), improvements in ground access, and, most important, attraction of the ‘‘critical mass’’ of flights needed to make them a viable alternative for both passengers and airlines[22].

2.7.1.3 GROUP 3: SPREADING DEMAND PEAKS

The third group of solutions are related to spreading the demand peaks by adopting an economic or administrative measure aimed at modifying the demand profile in a way that fits within the limits of the available capacity. There are two proposals to achieve this approach, one market-based and the other administrative.

A. Market-based measures

1. Peak-period pricing: This market-based approach uses prices as an instrument to regulate traffic demand. Commonly, it takes the form of surcharges (extra fees) on the use of the airport slots during busy hours of the day to encourage airlines to shift their flights out of the most congested periods to other less busy times or even to different airport sites.

2. Slot auctioning: In this case, the right to use the airport (landing or take-off) at a certain time during the day (slot) is sold to the highest bidder. In this way, the free market forces determine the cost, which is what users are willing to pay based on their perception of the value of the airport access at any given time.

B. Administrative measures

This approach is aimed at limiting the volume or type of air traffic that will be accommodated at an airport within the limits of some given capacity or acceptable level of delay as:

1. Traffic quotas and slot allocation:: Under this proposal maximum quotas are imposed on the number of aircraft landings and take-offs and/or passenger volumes permissible within the limits of some specified capacity of the runway system, the aircraft gates and/or the air terminal building.

2. Traffic flow control: Flow control is a procedure of administration of air traffic assisted by computer, which does not explicitly restrict the access to the airport. This technique focuses on the dynamic control of traffic volumes to and from an airport in response to overall regional or national demand. This is accomplished through settings with computerized continual adjustments of the times of arrivals and departures from airports throughout the system. Usually the delay occurs in less costly ways, for instance, on the ground at the departure airport or en-route rather than in a holding pattern at the destination airport.

Since the early work of Levine (1969), Carlin and Park (1970), and Borins (1978), economists have adopted these solutions by calling for the use of a price mechanism, under which landing fees are based on an aircraft's contribution to the congestion problem. See reference [23] for a comprehensive review. Practically, utilization of the airport facilities varies at the intra-day, and the congestion levels are varied during different periods of the day. Therefore, an airport 'peak load' congestion pricing mechanism was proposed. Different landing fees would be charged at different times such as, peak hours, where flights are charged higher rates than at the off-peak hours [24]. The deregulation in 1978 brought about the massive expansion of air travel and also the competitive tension between airlines since new airlines wanted to enter the markets. In 1985, "grand-father rights" institutionalized the slot ownership for current holders of slots allocated to domestic operations. These carriers may sell or lease their slots, and have to return a slot back to a pool of unused slots for re-allocation if it is used by the current holder for less than 80% of the time. This "use-it-or-lose-it" provision was initially designed to prevent non-competitive holding of slots, promote efficiency in utilizing runway capacity, and market entrance. However, there are two criticisms of this practice. The first is that the airlines do not own these slots, and the airport operator should be allowed to manage the allocation of these slots to assure safety, control congestion and maximize passenger/freight throughput. The second is that airlines are accused of being selective in choosing who is allowed to purchase slots from them, thereby preventing competitors from gaining access to useful slots. Vast amounts of literature have considered the peak-load pricing at airports. However, several of them stated that the congestion pricing mechanism has no (or just partial) place at an airport when the carriers have the market power, because the carriers themselves will internalize the congestion [25].

2.7.1.4 OPTION D: APPLICATION OF OPERATIONAL AND TECHNOLOGICAL INNOVATIONS.

Apart from the methods of reducing congestion and the resulting delays mentioned above, another solution to increase the airport capacity is through development and implementation of new technologies and innovations to maximise the efficient utilisation of the existing facilities. Some innovative operational practices could be considered to improve the utilisation of airport capacity, for instance:

- Checking-in at gate holding areas for high-density/shuttle operations where passengers have only carry-on luggage. This allows travelers to bypass the otherwise busy public concourse check-in counters.

- Adoption of common-use gate assignment operational strategies to maximise the utilisation of gate capacity as opposed to exclusive use of gates by airlines.

A number of studies investigated these solutions, such as Takakuwa and Oyama (2003), who performed a simulation analysis for the international departure passengers. They found that the addition of supporting staff to the regular staff had an effect. This addition made an efficient use of first and business class check-in counters for different types of passengers (economy and group class passengers) which reduced the processing time at the check-in counters to two thirds of the time performed by only regular staff [26]. A simulation analysis through the use of the queuing theory by Joustra and Van Dijk (2001) concluded that many different solutions can reduce the check-in time. One of the proposed solutions was using the common check-in counters instead of the dedicated airline counters. This will reduce the number of counters that are required at the departure terminals [27]. A bottleneck and stakeholder analysis was conducted by Bouland in 2007 to solve the terminal congestion at Amsterdam Schipol Airport and a set of solutions was proposed, such as self-service check-in systems. These systems would allow passengers to perform Online or mobile check-in and self-service drop-off points to check-in their hold bags [28]. A part of the applications of the innovative technologies is using the large aircraft types to transport passengers, such as A380. Using the biggest aircraft, means using fewer air traffic movements to transport the same number of travelers, or transporting more users within the same required number of operations. Additionally, using computer modeling and simulation is one of these innovative technologies. Here, computer models have been used widely to assess the revealing level of the services and to reduce congestion at airports. These models can improve the airport efficiency and the capacity management. Simulations of aircrafts movements on the runways, taxiways and other movements as well as pedestrians flow in the terminal building, and vehicles movement in the ground transportation system have been produced [10].

Most of the aforementioned solutions require passengers to perform the check-in process at the airport terminal. While, according to the European commission 70% of delays which are the main symptoms of the congestion problem are due to capacity limitations on the ground at airports not in the air. There is ongoing work to improve the Air Traffic Management system performance, but delay and congestion problems cannot be handled successfully if the performance of the airport on the ground is not improved. Therefore, the proposed solution has been presented in a way that will help to improve the ground segment performance and reduce the airport congestion by taking the entire passenger and baggage processes outside the main airport through adapting the new passenger/baggage dissociation concept. The dissociation of baggage from passenger travel has been discussed in this project as a prospective strategy to radically innovate travel services. Thus, the ultimate goal is to offer the end-to-end or a door-to-door baggage-free journey from the point of departure to the final destination. Such complete dissociation would occur both within the ground and the air segments of the passenger journey. The complete passenger/baggage dissociation has not been thoroughly investigated despite its obvious advantages regarding the capacity and congestion problems at airports, since the whole check-in and drop-off processes will be implemented outside the airport. The implementation of this concept is likely to be done in several phases which is still an open problem and subject to much research. However, this project delivers the idea of the baggage dissociation and it outlines the main challenges and the potential benefits. Also, it finds the methods that enable the implementation of this concept through presenting the idea of a new innovative baggage delivery network that is examined as a key enabling strategy of the end-to-end dissociation and the satellite terminals (OATs) that will off-load many services outside the airport.

CHAPTER 3

EVALUATION OF ARRIVAL AND DEPARTURE STATISTICS IN THE LARGEST WORLD AIRPORTS

3.1 INTRODUCTION

This chapter presents a discussion on data privacy, data aggregation, data regulations and other prevalent issues. Using public data sources such as Skyscanner, Flightradar 24, Flightaware and Planefinder, one week of arrival and departure data for over 100 of the world's largest airports have been collected. The data have been evaluated for the four main London airports, additionally, a developed Python interface can be used to query the data for other airports. In addition, research tasks where these data can be useful are outlined and include optimization of airport hubs, development of baggage dissociation concept, and predictive analytics of air traffic. Passenger satisfaction and passenger experience is discussed, including the effects of digital technology on the passenger experience. Finally, the chapter looks at the influence of passenger loyalty on the air transport industry.

3.2 UNDERSTANDING THE PASSENGERS EXPERIENCE CONCEPT

In general, customers have an 'experience' whenever he/she purchases a product or uses a specific service [29]. This experience can be made up of all the ‘clues’ that are available. The clues that help the experience are anything that can be sensed, perceived, or noticed regarding their presence or absence. For example, the physical setting, the quality of a product or a service, the price and the speed of the service coupled with an employee’s knowledge and behavior. Each clue contributes to providing the total customer experience [30].

Therefore, companies should focus on understanding the customer experience, by monitoring and modeling the whole experience. Shaw, stated that the main reasons for companies striving to achieve the best customer experience are [31]:

- Obtain and maintain the customer's loyalty in a competitive environment.
- Provide a differentiator so they can be set apart from other competitors.
- Increase their profits.

This rationale agrees with the notion that airports and airlines are encouraged to increase their profits by obtaining passenger loyalty. As outlined earlier, it is important for both airports and airlines to understand their passengers' experience to retain their loyalty and consequently improve their profits.

According to Berry et al., passenger experience has been described as the activities and interactions that passengers undergo in the airport terminal building [29]. It can be classified into two main groups: processing activities, and discretionary activities. Processing activities are the kind which should be finished by each passenger in sequence starting from arrival at the airport passing through the check-in process to security screening, immigration, and ending with boarding the aircraft. In contrast, discretionary activities are optional, unordered activities based on the passenger's choice.

The annual Airport Council report indicated that, passengers are the main stakeholders of any airport, therefore they should have the right to express their feelings, opinions and their satisfaction with the airport services [30]. Moreover, passenger needs must be investigated to specify what is important for them, and how both airlines and airports should respond to any inadequacy. Since a passenger's first impression of the airport facilities might influence their perceptions about the airport services, airports should provide comfortable and convenient facilities.

Many studies state that a competitive advantage can be gained through offering an excellent passenger experience. This matter makes the passenger experience a strategic priority for any airport. Passenger experience can be measured using numbers of customer satisfaction indicators. These include the following waiting times for: check-in, security, baggage, the availability of baggage carts, information convenience, immigration, and terminal facilities [31]. In fact, many airports are working hard to improve their efficiency to present positive passenger experience during the whole journey.

There are many factors that need to be considered in order to understand the whole passenger experience. This starts from preparing for the journey and progressing through various processing stages at both departure from and arrival to the airport. For example, this experience can be enhanced significantly for disabled and elderly passengers if the proposed solution of passenger/baggage dissociation has been adopted. The main issues that are identified by elderly people at airports are standing a long time waiting in queues for a check-in or security. Seating is required to be adjacent to the baggage claim information area. Transporting baggage is very challenging for elderly people at the airport, and ground transportation is required to be as close to the baggage-claiming hall as much as possible [32]. Free baggage travel, without the need to carry luggage, will make the entire journey significantly more attractive for elderly or disabled passengers and the concept of enhancing passenger experience is likely to be achieved in this case.

3.3 PASSENGERS AND TECHNOLOGY

Today, airlines and airports focus on improving their performance and providing services to their consumers by adapting more flexible technologies that deal with any issues in their operations. All these attempts are valued by passengers, especially the direct relation between passenger desires and the level of control they have over their journey. The 2016 Passenger IT Trends Survey cited that 85% of passengers reported a positive experience across the end-to-end journey. These positive feelings increased at those journey steps where passengers had choices and felt in control [33]. Now, more than half of passengers use some self-service technologies during their journey. For example, using mobiles phones for booking Online and check-in services. The same survey recorded that 91% of the passengers use the self-service check-in, since they prefer using technology rather than using face-to-face check-in. While for baggage services, the same survey reported that 76% of passengers in the future would use real-time baggage notifications on their mobile devices.

3.4 TECHNOLOGY AND IMPROVING PASSENGERS EXPERIENCE AT AIRPORTS

Airports represent the connection between airlines, customers and destinations. Specialists in the field refer to airports in the future as “airport cities”, as they have the characteristics and functions of independent cities. Airports have evolved significantly in the last three decades as result of the evolution of technology. Many studies show that large airports with technological access are more efficient and have less operational wastage. Therefore, air carriers looking to expand their operations look at these kinds of airports. The aim is to reduce their costs and increase the quality of their services that develop the passenger experience [33]. On the other hand, airport technology helps to provide alternative ways to increase airport throughput without construction or expensive capital investments. This provides an alternative for the construction of new facilities and helps significantly reduce congestion [34].

Some of the innovations and new trends for the future that have been implemented and are going to be implemented at airports are summarized as follows:

3.4.1 SELF-SERVICE KIOSK

IATA stated that fast travel allows passengers to have more control of their journey through self-service kiosks for flight rebooking, baggage tagging, travel document scanning, boarding and baggage recovery [35]. At the same time, airports have found that self-service kiosks are valuable tools in reducing queues. They allow the processing of a considerable number of passengers to be decentralized from the airport itself. These facilities allow better use of the airport staff resources and reduce bottlenecks.

3.4.2 ePASSPORT GATES AT THE AIRPORT BORDER CONTROL

As technology has evolved, automated border controls that are able to handle biometric passports or ePassports have been installed at airport terminals. These gates are automated and use facial recognition technology. It compares the passenger's face with the photograph that is recorded on a small chip included inside the passport, once the check-in is successfully completed the gate opens automatically [36].

3.4.3 SELF-SERVICE BAG DROP

According to SITA's 2015 Passenger IT Trends Survey, passengers thought that adopting widespread self-service baggage processing, was still far away. However, innovative self-service bag-drops and self-tagging solutions were developed to enable passengers to have more control over their journey. Furthermore, these facilities would improve the passenger experience through achieving high level of satisfaction regarding to the speed of the process. From another aspect, airports look for self-service bag drop off as the technology that will lower their operational costs and mitigate passenger congestion [37].

3.4.4 COMMON USE SELF SERVICE KIOSKS (CUSS)

To engage passengers with self-service technology and make them feel more in control of their flight events, new services are used to provide more information about what happens next. Beacon technology is one of these new services that provides indoor positioning to detect nearby objects. It is a low-powered wireless transmitter for Bluetooth signals over a radius of up to 50 meters that relies on sensors [38].

Bluetooth beacons have been installed in many airports. They use both passenger locations and flight schedules to send them any information related to their flights directly to their mobile device. Both airports and airlines are interested in using this technology, however; airports are ahead of airlines in many of the initiatives. A survey found that 61% of airports are planning to use beacons for check-in compared to 44% of airlines. SITA's report indicated that beacon technology will be used in the baggage process. Whereas, around 55% of airports and 44% of airlines plan to use beacon for baggage drop-off and collection processes, in which beacons can be informed of baggage drop-off and collection carousels prior to the arrival of baggage so passengers can estimate the required time that needed to collect baggage. Moreover, 40 % of airports and 43 % of airlines want to use beacon for baggage claim [39].

3.4.5 AIRPORTS AND BEACON TECHNOLOGY

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3.5 AIRLINES AND TECHNOLOGY

The airline industry has experienced a number of significant innovations over recent years. It is not surprising that airlines have been an eager adopter of automation. Airlines are responsible for two stages of the passenger journey, check- in and boarding. The literature shows that fast and efficient check-in is significant to passengers. Long check-in queues are argued to affect the passenger satisfaction at the airport. Also, inefficiency is considered as a major factor in a passenger's decision to change airline. Therefore, airlines have harnessed technology to enhance both their efficiency and effectiveness. Different automated services can be offered to improve the passenger experience. These include online ticket issue, online self-check in, using ePassports and calling passengers to the boarding area [41]. The airline industry is the area where the adoption of technology has grown rapidly. This adoption has increased the expectations of passengers as what and how the airlines offer services and products. Therefore, a greater majority of airlines, around 91%, intend to invest in internet of things (IoT) such as beacons and sensors. While 84% are planning to invest in business intelligence and predictive analysis [42].

3.6 AIRLINES AND INTERNET OF THINGS (IOT)

IoT provides multiple opportunities for airlines to improve their operational efficiency and at the same time increases their personalisation for passengers. Many airlines have experimented with IoT to implement projects that improve baggage handling, tracking pets in transit, equipment monitoring, and generating fuel efficiencies. This technology aspires to manage and improve stress-points during the journey. Infrastructure, such as baggage carousels, elevators, travelators, kiosks, bag-drop stations as well as boarding gates will be sensorized. This will enable staff and travelers to be connected and this connection will reshape the passenger experiences throughout the whole journey. For passengers, this can be translated into a better-informed journey. Many airlines have been using iBeacon technology to deliver flight details and gate information to their passengers. This information is used on their mobile devices to help them find their way to check-in desks or kiosk, lounges and gates.

3.7 BAGGAGE HANDLING SYSTEMS

In the past, airlines relied on point-to-point flights, which made the baggage handling systems easier since the data is shared between the passengers and the organisation itself. However, with time and due to an increasing number of alliances between airlines, the transfer of passengers has been increased . This increase means an increase in the transfer of baggage as well, a matter that affects the load on current baggage handling systems. This can have a significant impact on both the costs and the quality of the service. Most large international and domestic hub airports handle significant quantities of baggage transfer, which introduces many problems such as sorting, mishandling and losing. The sheer volume of baggage handled also raises the risk of congestion, routing errors and control problems. Furthermore, in many cases the physical size of the airport dramatically increases transporting times to and from the aircraft, which leaves less time for the actual sorting and handling of the baggage items. Therefore, the baggage handling performance is considered as one of the key links that provides good service quality for passengers [43].

There are at least five parties that are involved in the baggage handling process and each one of them adding different demand to the process:

1. Passengers ask for a hassle-free process that is reliable and fast and at the same time is combined with short transfers. Moreover, they ask for a process that can handle a wide range of baggage sizes, weights and shapes.

2. Airlines aim to combine the fleet utilization and the passenger satisfaction at minimum cost as possible. Error rates are very important in this case, because the costs of delivery and damage charges are borne by the airlines.

3. Airports aim to achieve maximum quality services at moderate investment. In fact, quality is an important factor for airports since passengers tend to attribute any delays or errors in baggage handling process to the airports.

4. Security agents add a strong demand on baggage handling process as they ask for in-line screening procedures to handle the suspect baggage.

5. Baggage Handling agents focus on costs and they want airports to provide the required systems and areas that allow the maximum ease of the baggage processing.

3.8 PASSENGERS SATISFACTION TOWARDS AIRPORT SERVICES:

From what has already been mentioned, there are various service providers that serve passengers at the airports starting from security control to check-in counters up to the luggage arrival. Many stages are present, including passport control, baggage access, boarding processes and the most stressful stage of the journey, standing in queues at the security checkpoint. In each stage passenger satisfaction is impacted by the service levels, and more than a third of the passengers reported negative emotions on their flight at these stages [43]. Baggage access time is one of the most important indicators for passenger satisfaction and performance evaluation of the service providers. Long waiting times for baggage can cause dissatisfaction among the passengers and such a service failure is likely to cause a decrease in the level of the perceived service quality. In fact, there are two different types of waiting time at airports, before departure and after arrival. The time spent before departure is based on the screening of passengers and baggage. This time varies according to the peak period, number of passengers and bags, passenger inter-arrival rate to the check-in queue[44]. Some of these metrics also affect the waiting time after arrival as well. Baggage handling is amongst the leading influence on passenger flows and airport processes, both for departing and arriving passengers [45]. Baggage access time is stated as processing time and revealed as the significant service attribute for passenger service evaluation. Waiting for baggage at the airport is a post-process delay at the final stage of the service delivery after a core service. More specifically, promptness and accuracy of baggage delivery have been revealed to be an important measure of the passenger satisfaction [46].

3.9 AIR TRANSPORT DATA

Most public datasets about Air Transport represent annual or monthly aggregated data that can be used for longer-term planning and airline network management. However, to devise and test new processes, more instantaneous data over shorter-time periods are required. In this project, one-week of actual arrival and departure data for 70 of the largest airport hubs representing over 130 large and small airports have been investigated. These airports have flight connections with almost 3,000 other airports. The flights dataset was extended with data about the characteristics of almost 200 aircraft types and different airport time zones. The flight datasets can be used to observe various statistics such as identifying peak and off-peak hours of the airports, finding the number of flights between hubs and non-hubs, allocating the busiest routes and understanding how different aircraft types are deployed. From these calculations, one can infer the average number of passengers and cargo volumes that have been delivered. This kind of information is not public and is not revealed by airlines for security and competition reasons. Usually, airlines have both regular data that arise from the sales and subsequent use of tickets, and from any special surveys that are undertaken for marketing or other purposes. Comparatively, a little of such data are published in a regular form and it is usually published aggregated, which is not sufficient and hard to extract useful statistical information. Also, the data that are systematically published by the aviation industry do not immediately reveal the relevant information to the inquiry.

For example, passengers tend to be treated not as individuals but as 'movements', such data may not be presented in terms of individual passengers but as passenger/kilometres. Another characteristic is the treatment of individual passengers who make a change of airline or plane during a journey for example from London to Honolulu via Chicago. In many cases, the data is reported as two or more passenger journeys. Particularly for domestic flights, where passengers depart and arrive at airports within the same 'statistical jurisdiction'. They may be counted twice, as may be 'interlining' passengers, who change from one aircraft to another at the airport. 'Transit' passengers, those who arrive and depart an airport on the same aircraft, less than 1% of UK airport passengers, tend to be counted once but sometimes not at all. The other issue of air transport data is 'privacy', the travel data is the largest most sensitive, most intimately revealing, most heavily computerized and name identified. Therefore, for all these reasons the agencies treat the travel data with a high level of privacy and are required to comply with government laws and regulations. For example, under the EU data protection rules, all personal data must be provided with a high standard of protection everywhere in the EU. Furthermore, any persons or organisations that collect and manage personal information must protect it from misuse and must respect certain rights of the data owners [47].

These data regulations create problems when the data are shared among parties in and outside of the EU. Moreover, even if the data were anonymized and made publicly available, there is the issue with business competition that restricts the data travel sources between airlines. Business competition can be very intense, IATA estimates there were over 1,300 new airlines established in the past 40 years and no company is keen to reveal their pricing strategies via publishing their data.

3.10 THE UTILIZATION OF AIR TRANSPORT DATA

It is useful to understand why there is a need for data in Air Transport sector, in fact these data are important for both airports and airlines in their decision-making processes. The analysis of these data is significant to predict the current and the potential future needs. This covers the requirements for developments in air transport markets, public policy priorities, and commercial requirements. Because, the aviation industry operates on small profit margins, it is very sensitive to any factors changes such as fuel price, currency exchange rates, competition, deregulation, and passenger attitudes [48]. Therefore, analysing this data can be used to perform the predictive analytics of the airports that help with improving decision-making. Such data covers the number of flights and their taxi times, the capacity of the airports and their historic operational behaviour. Combining their historic operational behaviour and confidence forecasting weather will significantly streamline airport operations. Such big data can create substantial economic value that is vital for creating new business models of airports with sufficient operations, decision-making, risk management and customer service [49]. Many travel data are generated by provisioning passenger services starting from flight searches and purchasing tickets. Such data indicate the trends, the destinations that are in demand, the preferences of passengers and how they make decisions when they choose their flights. Changes in the airline networks may be suggested when responding to route demands because the new flight routes would be viable. From another aspect, these data can be used to evaluate hubs performance which is vital for providing logistical decisions. These decisions support airlines at the airports through the provision of operations simulation, scheduling, optimization and planning. Such planning includes capacity planning, passenger flow management, performance measurements, baggage and cargo handling, etc.…

In spite of the large amounts of data that has been produced by Air Transport Industry, see Table 4.1, there are still huge opportunities to devise how to make the best use of these data. This use of data requires developing appropriate system models for predictive analytics. The data collection processes are usually driven by the system KPIs whose selection is non-trivial (different KPIs are likely to lead to different dynamics of the systems being managed). Some KPIs are adaptively modified to account for an abnormal behaviour of the systems, such as airline network disruption due to bad weather, or unexpected aircraft maintenance. While other KPIs are adjusted against the longer-term effects such as seasonal adjustment of revenues. All these KPIs can be used as pointers, to show where more work and improvement has been performed [49].

Table 3.1 Public Sources Of Air Transport Data

Data Sources	Data Type
Bureau of Transportation Statistics (1)	Data and Statistics, Airlines and Airports, Passengers, National Transportation Statistics, Databases, Highway
Eurostat (2)	Database, Air transport infrastructure, Air transport equipment, Air transport - Enterprises, economic performances and employment, Air transport measurement - freight and mail, Air transport measurement - traffic data by airports, aircraft and airlines, Air transport - regional statistics
Civil Aviation Authority (3)	Data and analysis, Airports, Airlines, Flight punctuality
Air Traffic at UK Airports (4)	Traffic at UK airports: annual, 1950 onwards, Punctuality at selected UK airports: time series, International passenger movements at UK airports by country of embarkation or landing: time series, Proportion of transfer passengers at selected UK airports: time series ,Mode of transport to selected UK airports: time series, Purpose of travel at selected UK airports: time series ,UK airports (map)
Datahub (5)	Traffic Scotland, Global airports, US Airline on-time Performance, Australian Domestic, Regional and International Airline Activity – Time series
Open Flights: Airport and Airline Data (6)	Airport, Airline, Route , Schedule and License
Statista (Not Free) (7)	Passenger traffic at worldwide airports by region May 2016,Cargo traffic at worldwide airports by region May 2016,Cargo traffic at worldwide airports by region May 2016,Countries with the highest quality in air transport infrastructure 2016/2017,Countries with the highest quality in air transport infrastructure 2016/2017,Finland: airport infrastructure maintenance expenditure 2004-2014,Finland: airport infrastructure maintenance expenditure 2004-2014,Mexican airlines - monthly domestic scheduled passenger service 2015-2016,Mexican airlines - monthly domestic scheduled passenger service 2015-2016

(1) https://www.bts.gov

(2) https://ec.europa.eu/eurostat/data/database

(3) https://www.caa.co.uk/Data-and-analysis

(4) https://www.gov.uk/government/statistical-data-sets

(5) https://datahub.io/search

(6) https://openflights.org/data.html

(7) https://www.statista.com

3.11 ARRIVAL AND DEPARTURE DATA RECORDS

In this project, the second week of June 2016 arrivals and departures data for 70 largest airport hubs have been collected. This data can help to test and analyze new concepts and solutions in designing and organizing the airline networks. Note that this data does not involve operational nor capital expenditure costs, which are considered as the critical factors that influence the whole air transport industry.

The data records for each airport arrivals, include the following reported items:

Flight number, aircraft type, origin of airport name and its ICAO/IATA code, ETD, and TOA. An example of Heathrow airport arrivals has been presented in Appendix A.1.

The items for the departures are: flight number, aircraft type, destination airport and its ICAO/IATA code, ETD, and TOA. An example of Heathrow airport departures has been presented in Appendix A.2.

The collected data are stored in CSV files within a hierarchical sub-directory structure. Before the data can be analyzed, the first task is to pre-process the raw data to remove several inherent issues. The data processing was carried out by scripts written in Python to exploit its functionality in working with regular expressions. Thus, the raw data are first parsed to check the records match the expected CSV pattern. About 10% of the records were found not to comply, due to inclusion of extra or forgotten commas, or missing the end-of-line character that separates two records. These records were corrected by pattern matching techniques in several parsing rounds until no incorrect record was found. Then straightforward to identify the missing values and replace them with some distinctive characters, a question mark has been used. Similarly, it was necessary to check all the record values to see whether they comply with the expected format or not. For instance, ICAO airport codes are a group of 4 capital letters, whereas IATA airport codes are formed of 3 capital letters, an example of the aircrafts types and their relative codes are presented in Appendix B. This task was complicated by the use of non-standard codes for airports and aircrafts, in around 10-15% of the cases. Especially, in data for the US area, some airports are designated by FAA codes instead. Moreover, the flight numbers generally do not seem to have any standardized format. Even though, in many cases it is possible to identify the operator from the flight number. However, the actual operator may be different due to flight sharing schemes that many airlines are involved in. In some cases, either only an ICAO or an IATA code was provided. For simplicity, ICAO codes to denote both airports and aircraft, have been used. Noting that, if an ICAO code was missing, it would be supplied from another CSV file that has been obtained from the ICAO website. However, even ICAO aircraft codes are not unique nor complete. For instance, the aircraft code may be shared by several versions or modifications of the same aircraft type. Another problem was encountered, which is the use of non-English characters in airport names. Those characters cause difficulties when importing the CSV files into the Excel spreadsheet. Therefore, those non-standard letters were identified, and manually corrected by assigning each of these letters to their corresponding English letters. The arrival and departure times were sometimes missing for days of the week so the time zones for these missing values were inferred from the preceding or following data records. Trials were attempted to convert the departure and arrival times to UTC (Universal Time Coordination) as shown in Table 3.2. This was a straightforward task for the times that are given for the main airports among the selected 70 airport hubs. However, the times for originating or terminating airports outside the airport hubs have the problem of not being unique. The reasons for these other airports are often their location is in very diverse geographical areas. The other issue that encountered was some time zone acronyms could relate to as many as four different time zones. Even though, it is possible to decode the correct time zone for a given airport. This is achieved by knowing its geographical location; however, such data are not available from the Internet for smaller and less often used airports. The python script that has been used to convert the time zones in Appendix H.

Table 3.2 Converting Different Arrival Time Zones To UTC Time Zone.

Raw Data					Processed Data		
Aircraft Type	Destination	Code	Departure	Arrival	Aircraft Type	Destination / Code	Arrival
B77W	Montreal-Trudeau	CYUL	Thu 14:55 BST	Thu 16:38 EDT	B77W	CYUL	Thu 13:55 UTC
A321	Copenhagen	CPH/EKCH	Thu 14:54 BST	Thu 17:21 CEST	A321	EKCH	Thu 13:54UTC
A333	Charlotte / Douglas Intl	KCLT	Thu 14:52BST	Thu 18:17 EDT	A333	KCLT	Thu 13:52 UTC
B788	Indira Gandhi Int›l	DEL/VIDP	Thu 14:51BST	Fri 03:02 IST	B788	VIDP	Thu 13:51UTC
A319	Geneva Cointrin Int›l	GVA/LSGG	Thu 14:50 BST	Thu 17:01 CEST	A319	LSGG	Thu 13:50UTC
A320	Barajas Int›l	MAD/LEMD	Thu 14:48 BST	Thu 17:35 CEST	A320	LEMD	Thu 13:48UTC
A321	Beirut Air base / Rafic Hariri Int›l	BEY/OBLA	Thu 14:47BST	Thu 21:01 EEST	A321	OBLA	Thu 13:47 UTC
B737	Aberdeen	ABZ/EGPD	Thu 14:46 BST	THU 15:50 BST	B737	EGPD	Thu 13:46 UTC
A321	Leonardo da Vinici (Fiumicino Int›l)	FCO/LIRF	Thu 14:45BST	Thu 17:36 CEST	A321	LIRF	Thu 13:45 UTC

3.12 EVALUATION OF ARRIVAL AND DEPARTURE DATA

When the clean and the corrected raw data has been evaluated, a combination of Python scripts and processing in Excel spreadsheets were used. The latter was deployed to generate tables, graphs and other data visualizations. Data processing is performed in several stages. It was found useful to generate new CSV files containing results of the intermediate processing steps. Also, it is particularly beneficial when the processing pipeline is not serialized, but various processing steps are combined in a tree-like structure as shown in Figure 3.1.

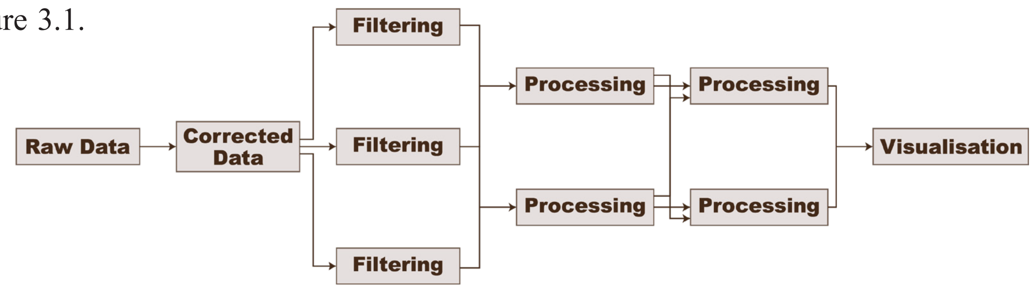

Figure 3.1 Data Evaluation And Visualization

For instance, the filtering step usually removes data fields that are not relevant to the problem at hand. It is often easier to process and combine these intermediate data files than to devise how to work directly with the root data file. More importantly, it was recognized that some other supporting data are required in processing the arrival and departure data. Specifically, compiling a new data file containing typical aircraft characteristics, a sample shown in Table 3.3. Appendix C contains the aircraft specifications for over than 200 aircrafts that have been collected and stored in a CSV file format. It includes weight characteristics, payloads, maximum range, fuel and seating capacity that can be used to obtain the payload-range curves and to determine maximum loading of the aircraft including the delivery efficiency.

Table 3.3 Data Sample Of Aircraft Characteristics For Most Common Airbus And Boeing Aircraft Types.

Code	Type	Cargo/kg	Typical Seats	Max Seats	Fuel / L	Range / km
B767	767-200	33270	181	255	63220	9400
B767	767-200ER	35560	281	255	91380	12200
B77F	Freighter	103000	N/A	N/A	181283	9200
B738	737-800	20540	160	189	26020	5400
A306	A300-600R	39700	266	361	68160	7700
A30B	A30B	37495	266	345	N/A	6667
A310	A310-200	33550	187	279	54920	4000
A310	A310-300	33460	187	279	75470	5600
A318	A318-100	13300	107	117	23860	2750-6000
A319	A319	29840	124	156	24210	6900
320	A320-200	18600	150	180	23860-29840	5350-5550
A320	A320-200	18600	150	180	23860-29840	5350-5550

Also, a CSV file for airports was created, a sample is shown in Table 3.4. Appendix D contains the details for over than 2000 airports. The file contains name, location (city and country), code designators (ICAO and IATA/FAA), the time zone shift against UTC, latitude/longitude coordinates and the size of the airport (small, medium or large) note that, the categories are determined by the number of the annual emplacements that are handled by each airport (a small airport handles 0.05 to 0.25% of the country's annual passenger boarding, a medium airport handles 0.25 to 1% of the country's annual passenger boarding, a large airport handles over 1% of the country's annual passenger boarding) [50]. This file is partly sourced from other existing similar files that were discovered on the Internet. However, data for small airports (time zones and locations) and many medium size airports must be searched and included manually, which was a very time-consuming process and this file like the aircraft specifications is the first that contains all of this data in one file.

Table 3.4 Airports Details Data Sample.

Airport	IATA/ FAA	ICAO	City	Country	Time Zone	Type	Lati-tude	Longitude
Keflavik International	KEF	BIKF	Reykjavìk	Iceland	0	large	63.985	-22.606
Reykjavik	RKV	BIRK	Reykjavik	Iceland	0	medium	64.130	-21.941
Sault Ste Marie	YAM	CYAM	Sault Ste Marie	Canada	-5	medium	46.485	-84.509
Campbell River	YBL	CYBL	Campbell River	Canada	-8	medium	49.951	-125.271
Brandon Municipal	YBR	CYBR	Brandon	Canada	-6	medium	49.910	-99.952
Cornwall Regional	YCC	CYCC	Cornwall	Canada	-5	medium	45.093	-74.563
Nanaimo	YCD	CYCD	Nanaimo	Canada	-8	medium	49.055	-123.870

3.13 THE GENERATED STATISTICS

Several statistics have been generated from the dataset to show how to utilize these data to support the idea of dissociation. For example, calculating the number of the arrivals and the departures to know the number of bags that can be handled at unit time at the airport to see if there enough capacity to support the dissociation or not. Also to show how different statistics can be calculated from these data that can be useful in many business models. First, an evaluation of the aircraft types that are deployed to perform flights to/from the largest airport hubs, has been made as shown in Table 3.5. It is obvious, that the most popular aircraft types are Airbus A320 and Boeing B738 which are used on short to medium routes around the world. These aircrafts are especially popular by low-cost airlines who often operate a large fleet of just one aircraft type to achieve significant acquisition and operational cost reductions such as Ryanair that operating only B738. The aircraft type statistics differ among Europe, Asia and America probably reflecting the different markets, habits and flying attitudes of passengers.

Table 3.5 The Aircraft Type Statistics For One Week Of Data In70 Largest Airport Hubs.

Type	Percentage %	Type	Percentage %
A320	19.1	B739	1.9
B738	18.1	B763	1.5
A319	7.3	A332	1.5
A321	6.9	CRJ7	1.4
B737	6.2	B752	1.4
E170	3.3	B772	1.4
A333	2.5	DH8D	1.1
CRJ9	2.1	B733	1
E190	2.1	E135	1

Next, many statistics have been produced for London airports for example flights to/from airports within Heathrow, Gatwick, Luton, Stansted and Southend have been evaluated, with the first two airports being considered to be hubs by themselves. The basic data about these airports are given in Table 3.6. While Table 3.7 lists the most connected airports from these five London airports, noting that the number of flights is counted over one week of the present data.

Table 3.6 Basic InformationAabout London Hub Airports.

Airport	Heathrow	Gatwick	Luton	Stansted	Southend
IATA	LHR	LGW	LTN	STN	SEN
ICAO	EGLL	EGKK	EGGW	EGSS	EGMC
Latitude	51.478	51.142	51.875	51.885	51.571
Longitude	- 0.461	- 0.190	- 0.368	0.235	0.696
Elevation	83	202	526	348	49
Time zone	+ 01:1	+ 01:1	+ 01:1	+ 01:1	+ 01:1
Runways	2(3)	1	1	1	1
Annually Pax	75 mil	40 mil	12.2 mil	22.5 mil	0.9 mil

Table 3.7 MostFrequent Origins And Destinations In One Week For London Hub Airports.

HEATHROW				GATWIEK				LUTON				STANSTED				SOUTHEND			
Arrivals		Departures		Arrivals		Departures		Arrivals		Departures		Arrivals		Departures		Arrivals		Departures	
EIDW	153	KJFK	146	LEBL	159	EIDW	207	EKCH	83	EKCH	93	EIDW	102	EIDW	125	EHAM	22	EHAM	23
KJFK	145	EIDW	136	LEMG	151	LEMG	143	EHAM	69	EHAM	62	EGPH	102	EGPH	100	LPFR	18	LPFR	18
EDDF	141	EDDF	130	EIDW	147	LEBL	135	LEBL	66	EIDW	55	EGPF	83	EGPF	79	LEPA	12	LEPA	13
EHAM	136	EHAM	121	LPFR	126	LPFR	128	LLBG	52	LEBL	53	LIRA	65	LIRA	64	LEMG	12	LEMG	12
EDDM	108	LFPG	95	EHAM	126	EHAM	113	LEPA	50	LROP	51	EDDB	64	EDDK	53	LEAL	12	LEAL	12
LFPG	104	EDDM	93	EGAA	115	LEAL	96	LPFR	46	LLBG	51	LIRP	62	LEMG	52	LFPG	7	LFPG	7
OMDB	100	LSGG	92	LEMD	111	EGAA	92	LEMG	46	LHBP	51	EDDK	55	EDDB	52	LEBL	7	EGJJ	7
LSZH	97	LSZH	90	LEAL	110	LIPZ	91	EGPH	41	LEPA	47	LEMD	54	LEMD	49	EGJJ	7	LEBL	6
LSGG	97	LEMD	85	LIPZ	109	EGJJ	91	EGAA	41	LEMG	43	LIME	50	EGAA	49	LEIB	6	LIPZ	4
LEMD	88	OMDB	79	EGJJ	104	LFMN	90	LEAL	39	LPFR	40	EPMO	50	LIRP	48	LIPZ	4	LEIB	4

The airline industry has changed tremendously in the last two decades. In the middle of the 90s, a new type of airline, known as low cost carriers, emerged in the markets. Appendix E contains all the low-cost carriers with the relevant IATA, ICAO codes, country, start and ceased year. Moreover, the airline industry witnessed an increasing number of mergers that affected business models, that used to be clear and precise, and which business model provided what type of service. Therefore, these aspects are enough causes to analyse the air transport data to assign the new business models in the market and to see what factors that might influence these models. For example, by analysing the arrival data record for Heathrow airport that contains 4987 flights we notice that around 89% of flights are international while the domestics flights were only 11% and most of them carried by British Airways, as depicted in Figure 3.2. The arrival data record for Southend Airport showed that 100% of the flights are international, and moreover all the flights are carried by EasyJet using one type of aircraft which is A319.

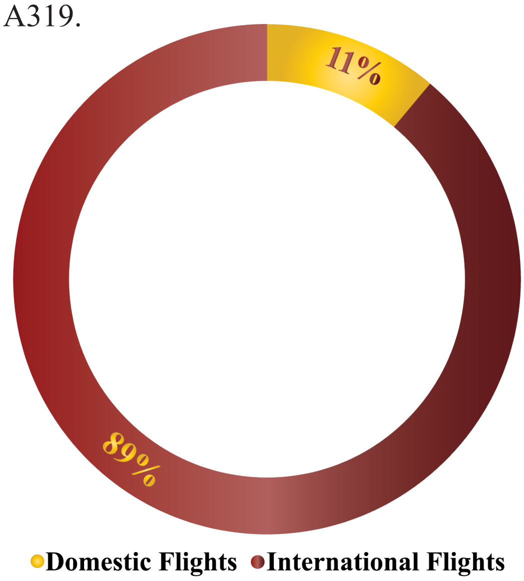

Figure 3.2 Domestic VS. International Flights For Heathrow Airpor

In fact, the differences among airports mainly reflect the presence of different airlines (traditional versus low-cost) and each one has its own different routes. Many statistics can be obtained from processing the aviation data, such statistics which provide useful information about the airport's activities, the number of passengers, volume of handled freight, punctuality etc. Another statistic for London airports is to see how different aircraft types are deployed among London airports, the results showed that the most frequent aircrafts types are A320, A319 and B738 as displayed in Table 3.8.

Table 3.8 Most Frequent Aircraft Types In One Week For London Hub Airports

GATWICK				LUTON				HEATHROW				STANSTED				SOUTHEND			
Arrivals		Departures		Arrivals		Departures		Arrivals		Departures		Arrivals		Departures		Arrivals		Departures	
A320	1748	A320	1574	A319	536	A320	731	A320	1315	A320	1163	B738	2388	B738	2311	A319	110	A319	109
A319	1683	A319	1503	A320	465	A319	497	A319	864	A319	779	A319	395	A319	388	......	......	......	......
B738	533	B738	522	B738	270	B738	300	A321	487	A321	418	A320	59	A320	55	......	......	......	......
A321	271	A321	268	A321	95	A321	141	B77W	283	B77W	252	D328	22	D328	34	......	......	......	......
B772	131	B772	129	B734	25	B734	24	B772	233	B772	226	AT72	14	A321	17	......	......	......	......
E190	129	E190	110	B739	13	B739	11	B744	217	B744	203	DH8D	12	E190	13	......	......	......	......
B788	53	B744	52	B752	11	B752	9	B763	211	B763	195	E190	11	AT72	13	......	......	......	......
B744	52	B788	49	B763	8	B737	8	A388	209	A388	182	A321	11	A332	13	......	......	......	......
A332	49	B763	49	B733	8	GLF4	7	B789	139	B789	119	MD11	10	DH8D	11	......	......	......	......
B763	48	A332	49	CL60	6	B763	7	B788	126	32A	114	B77L	10	B77L	10	......	......	......	......
A388	39	B737	39	MD82	4	B733	7	A333	126	B788	111	32A	10	32A	9	......	......	......	......
B737	35	A388	37	GLF4	4	MD82	4	32A	109	A333	106	B772	8	B763	8	......	......	......	......
A333	25	A333	26	GLEX	3	GLF5	3	B737	73	B737	76	A332	7	B772	7	......	......	......	......
B789	24	B789	24	F2TH	3	GLEX	3	A332	60	A332	49	B763	6	GLEX	4	......	......	......	......
AT72	22	B733	24	CRJ9	2	CL60	3	B738	58	B738	48	B748	5	74F	4	......	......	......	......
B733	13	AT72	18	GLF5	1	F900	2	A346	49	A346	48	B744	4	GLF4	3	......	......	......	......
B752	12	B752	12	F900	1	F2TH	2	777	49	B764	38	74F	4	MD11	2	......	......	......	......
A310	4	32B	11	CL30	1	GLF6	1	B773	39	B773	36	GLF4	3	GL5T	1	......	......	......	......
F100	3	A310	5	BE40	1	GL5T	1	B764	37	767	31	GLEX	3	FA50	1	......	......	......	......

Moreover, to identify peak and off-peak hours of airports, Figures 3.3 and 3.4 compare the total number of flights for three major airport hubs selected in Europe, Asia and America. These curves confirm that there are almost no flights for several hours after midnight (noise abatement, economical and passenger convenience measures). The total daily arrivals showed a three-modal distribution (three peaks) for Atlanta airport while a uni-modal distribution was found for Heathrow airport with the busiest day of the week being Monday. On the other hand, Beijing sees the busiest travel times to be over the weekend, from Friday to Sunday.

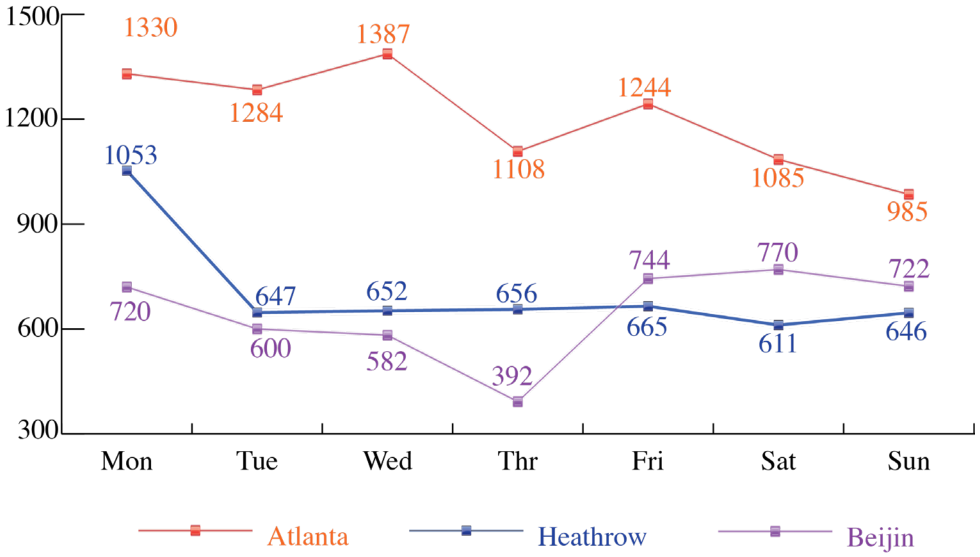

Figure 3.3 Number Of Arrivals Over A Typical Weekday For 3 Selected Large Airports.

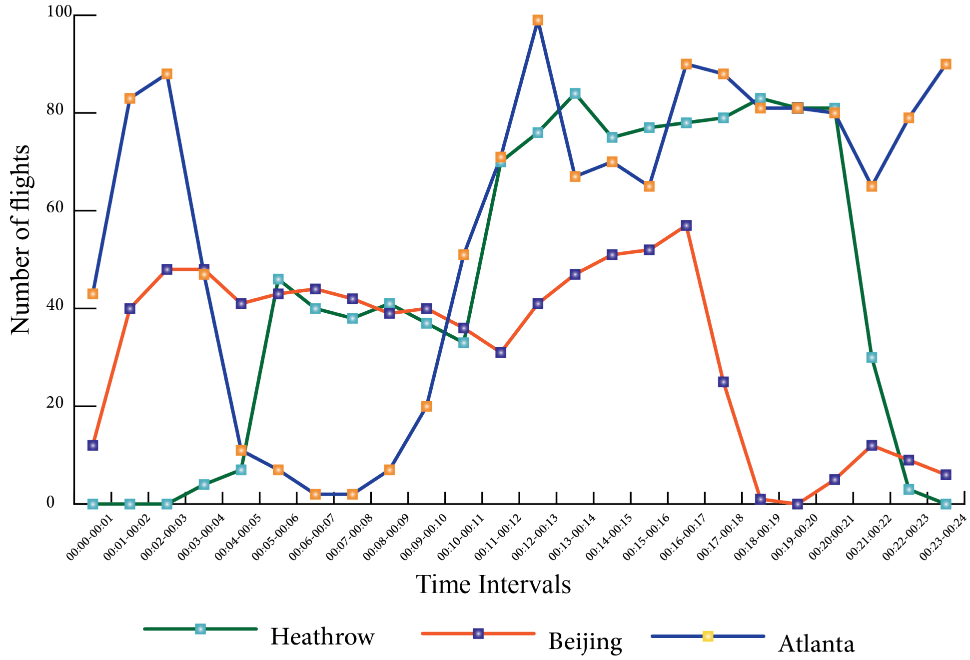

Figure 3.4 Hourly Number Of Arrivals Distribution Over The Busy Day For The 3 Selected Large Airports

The distribution of hourly arriving and departing passengers during the busiest day for each airport of London city, are calculated and the results shown in Table 3.9.

Table 3.9 The Hourly Arrival And Departure Passengers During The Busy Day For Five London Hub Airports.

Time period	Heathrow/ Mon	Luton/ Fri	Stansted/ Fri	Gatwick/ Fri	Southend/ Fri
00:00 - 01:00	312	1065	1857	4744	156
01:00 - 02:00	0	2204	1413	3068	0
02:00 - 03:00	0	0	752	1784	0
03:00 - 04:00	0	0	0	0	0
04:00 - 05:00	2206	0	440	0	0
05:00 - 06:00	3495	0	0	785	0
06:00 - 07:00	22830	180	1618	8389	0
07:00 - 08:00	12958	2057	6483	9369	0
08:00 - 09:00	11876	2470	3813	10099	0
09:00 - 10:00	11852	1978	1824	7598	312
10:00 - 11:00	11984	2368	2547	8455	0
11:00 - 12:00	10778	2010	5538	8499	0
12:00 - 13:00	19551	2346	6153	6646	312
13:00 - 14:00	22061	2546	4395	7945	312
14:00 - 15:00	23632	2105	3081	8243	0
15:00 - 16:00	22693	1437	5115	6735	0
16:00 - 17:00	21464	1736	5183	7407	468
17:00 - 18:00	18367	1943	4843	8477	156
18:00 - 19:00	22442	2262	6200	7681	312
19:00 - 20:00	21586	4154	6507	5773	0
20:00 - 21:00	18616	1334	3769	5792	0
21:00 - 22:00	16804	1673	1853	7827	312
22:00 - 23:00	6430	2043	4361	8538	624
23:00 - 24:00	492	4177	8076	0	0

Finally, the maximum number of arrivals and departures over one week to London airports have been produced as shown in Table 3.10. Note that, the number of passengers was calculated depending on the maximum (high-density) number of seats for the aircraft type, since the number of arriving or departing passengers on a given flight cannot be known exactly for privacy and business reasons as mentioned earlier.-

Table 3.10 The Total No. Of The Flights And Maximum No. Of Passengers For Both Arrivals And Departures.

	HEATHROW				GATWICK				LUTON				STANSTED				SOUTHEND			
Days	Arrivals		Departure		Arrivals		Departure		Arrivals		Departure		Arrivals		Departure		Arrivals		Departure	
Sunday	85917	425	146261	744	194847	646	175674	576	2808	18	2808	18	77450	418	79063	434	36121	215	44937	261
Monday	143902	738	140674	730	298316	1053	271106	919	1404	9	1716	12	80779	439	86900	474	34563	196	51695	298
Tuesday	94916	506	65730	339	192608	647	159837	553	1872	12	1560	10	64353	347	55696	307	28037	161	32893	197
Wednesday	129183	666	123597	628	195034	652	173819	614	2652	17	2496	16	83021	446	71228	398	33592	197	38864	229
Thursday	149140	765	141056	628	194995	656	192552	651	2808	18	2808	18	79807	425	82220	453	40324	233	48301	273
Friday	149841	765	139433	720	197097	665	170974	583	2964	19	2808	18	85822	467	84824	462	42198	241	49195	282
Saturday	136244	682	138605	714	187614	611	169866	567	2652	17	2808	18	71520	384	75773	417	36520	206	44976	259

As a conclusion this kind of statistics can be used to infer the distribution of baggage weights and baggage volumes in terms of the number of luggage pieces weights that are delivered hourly and daily to the airports. This is important to evaluate the feasibility of baggage dissociation. In addition, it helps to understand whether there is enough capacity in the current system to support the baggage dissociation or not.

3.14 SUMMARY

Even relatively short segments (one week) of flight data in this project can be very useful to elucidate insights into the structure and the operation of airline networks. This data can be used to devise economic models or to optimize transportation of passengers and cargo delivery. Since more detailed data about flights (number of passengers actually travelled, cargo volume delivered, number and weight of baggage) are either subject to privacy issues or business secrets, it may be sufficient that the authorities such as (CAA, FAA, governments, airports, airlines) report, for example, average flight occupancy per aircraft, or average number of flights per day. Such similar data are sufficiently general to constrain their value (for reasons mentioned above), and at the same time, to be more informative than the typically reported monthly or annually aggregated values. Nevertheless, one week of flight data has been used to infer (approximate) the values needed to identify the distribution of baggage weights and baggage volumes that are delivered hourly and daily to London airports.

CHAPTER 4

BAGGAGE WEIGHT AND BAGGAGE FEES

4.1 INTRODUCTION

Another set of data which is important for evaluating efficiency and concepts in baggage delivery services in air transport is concerned with baggage weights and pricing of baggage delivery services. Unfortunately, these data are more difficult to obtain as they are proprietary and not disclosed by the airlines or the airports. The intention here was to perform a preliminary investigation of the baggage dissociation concept where baggage is delivered independently from passenger travel. A number of benefits resulting from the dissociation are identified and discussed. In addition, a case study involving 12 most commonly used aircraft types to investigate the feasibility of baggage dissociation was analyzed.

4.2 UNBUNDLING PROCESS AND BAGGAGE FEES

Back to the summer of 2008, when there was a significant jump in the jet fuel prices and the price of crude oil barrel reached $140, many airline companies stripped out their previously free services [51]. The companies then started charging passengers for their services more than basic transportation. From that time, airlines started the process of unbundling. In other words, separating various costs for their different services, such as security checks, baggage checks, meals, seat assignments, Wi-Fi use, and early boarding. Thus, the ticket costs one price with additional fees for extra services, in this case passengers only pay for the services they use. The obvious unbundling in the airline industry, started when the US airlines started charging for checked bags in 2008 [52].

Due to the recession of 2008, it was assumed that the global industry losses would reach $11 billion in 2009. While in contrast, categorized as "ancillary revenue", the industry witnessed the introduction of the unbundling process in which more fees were charged by legacy and low-cost airlines. "Ancillary revenue" from service fees generated $10.25 billion in 2008. In the first nine months of 2009, the revenue for more than one checked bag alone was around $2 billion [53]. Over the years, baggage fees have had a huge impact on the airline's profits. For around 3% of passengers, the related revenues of baggage fees were $17 billion, for the period 2010-2014.

It is obvious that airlines can make revenue from the services that they offer. However, as a preliminary investigation, this section provides a brief discussion (due to limited data sources) whether it is beneficial for airlines to isolate passengers from their baggage, or not.

To answer this question a knowledge of the following is required:

1. The number of passengers in the plane to estimate the total weight of luggage in each journey, i.e. Total Luggage Weight (TLW):

TLW= No. of passengers * Weight allowed per passenger.

Noting that the weight allowed per passenger is divided into two to three categories, ranging between 30 – 40 kg according to the passenger class: tourist, special, first or business etc…

2. Luggage weight affects the amount of fuel consumed in each trip or flight, less weight means less fuel consumption. Moreover, extra fuel can be added instead of the luggage weight and in this case the profit can be achieved from not carrying luggage, results from avoiding the transit phase and paying airport charges. These charges include: landing, parking, passenger services, security, noise-related and emissions-related aircraft charges. Note that, these charges are set by ICAO Policies for Airports and Air Navigation Services [54].

3. There is another scenario for achieving extra profits, which is carrying extra passengers instead of the luggage weight in the available spaces of the airplane. Note that this assumption is theoretical and depends only on exchanging weights, despite the new design of the passengers only aircrafts, or the required new seat allocation.

In any case, the expenses incurred in the carriage of luggage and delivery of this luggage to their rightful owners must be considered.

4.3 AIRCRAFT WEIGHT CALCULATIONS

There are two types of certified weight limits according to the authority responsible for issuing the certificate. They are, the weights certified by the manufacturer during the design and certification process of the aircraft, and, the weights certified by the operator. Note that the weights certified by the operator usually depend on the configuration /specification phases [55].

4.3.1 THE MANUFACTURER CERTIFIED WEIGHTS

These weights are specified during the aircraft design and certification phase, and are noted in the manufacturer's specification documents, and in the aircraft type certificate, such as: Aircraft Weight & Balance Manual (AWBM) and Aircraft Flight Manual (AFM).

The manufacturer certified weights can be divided into the following weight groups:

- Maximum Taxi Weight (MTW): is the maximum weight for ground manoeuvre as limited and / or authorized by the airplane strength and airworthiness requirements. (This includes the weight of fuel for taxiing to the take-off position).

- Maximum Take-off Weight (MTOW) means the maximum weight for take-off as: limited and / or authorized by the airplane strength and airworthiness requirements. This is the maximum weight at the start of the take-off.

- Maximum Landing Weights (MLW) means the maximum weight for landing as limited and / or authorized by the airplane strength and airworthiness requirements.

- Maximum Zero-fuel Weight (MZFW) means the maximum weight permitted before loading the usable fuel and other specified usable fluids. The MZFW is limited and / or authorized by the strength and airworthiness requirements.

4.3.2 THE OPERATOR CERTIFIED WEIGHTS

As mentioned earlier, there are some weights that can be established by the operator, which vary according to the configuration and specification of the aircraft. These weights include the Operating Empty Weight (OEW) and the Maximum Structural Payload (MSP) [55].

- The Operator's Empty Weight (OEW): is the weight of the aircraft that is prepared for service. This weight is the sum of the Manufacturer's Empty Weight (MEW), Standard Items (SI), and the Operator Items (OI).

- Manufacturer's Empty Weight (MEW) - is the aircraft's weight as it leaves the manufacturing facility. This generally consists of the structure weight, and weights of the power plant, furnishings, systems and other items of equipment that are an integral part of a particular aircraft configuration. MEW also, includes those fluids contained in the closed systems only.

- Standard Items - Equipment and fluids are not considered an integral part of a particular aircraft. These items may include the following: (a) Unusable fuel & other unusable fluids, (b) Engine oil, (c) Toilet fluids & chemicals, (d) Fire extinguishers, pyrotechnics & emergency oxygen equipment, (e) Galley structures, (f) Supplementary electronic equipment.

- Operator Items – These include Personnel equipment & supplies necessary for a particular operation. Such items may vary for a particular aircraft and may include the following: (a) Crew & Baggage, (b) Aircraft documents, (c) Food & beverages, (d) Passenger seats, (e) Life rafts and life vests.

- ➢ Maximum Structural Payload (MSP), means the maximum design payload (made up of passengers, baggage, and cargo), calculated as a structural limit weight. For any aircraft with a defined MZFW, the maximum payload can be calculated as the (MZFW) minus the (OEW).

4.4 BUILD-UP THE OPERATOR WEIGHT FOR THE AIRCRAFT

Figure 4.1 shows the composition of weight categories, which are reflected in most of the commercial aircrafts. Starting from the Manufacturer's Empty Weight (MEW), then adding elements to make the aircraft ready for its operation.

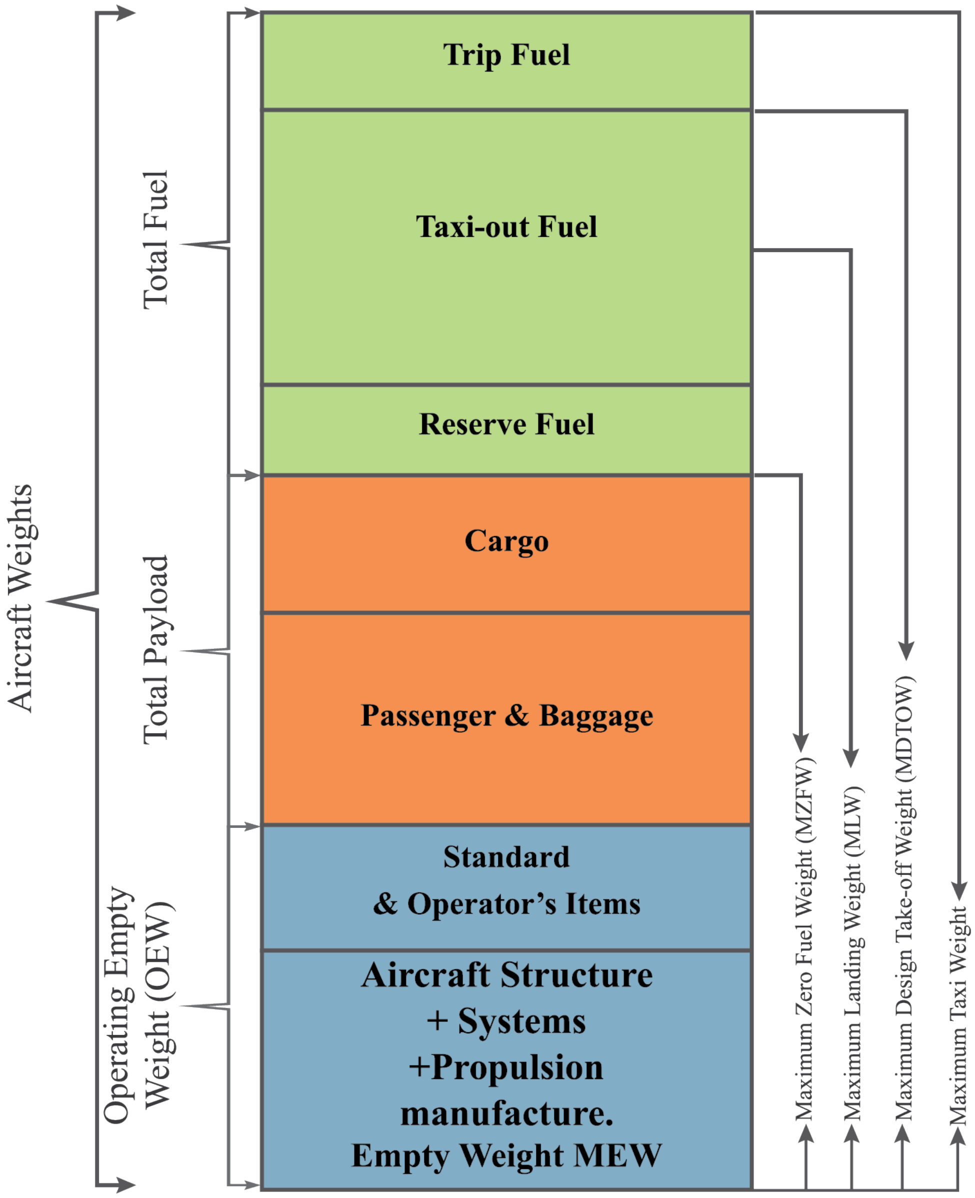

Figure 4.1 The Build-Up Weight Of An Aircraft

Also, from Figure 4.1, one can conclude some mathematical perspective that is summarized as [55]:

- Operating Empty Weight (OEW): It is the sum of Manufacturer's Empty Weight (MEW), Standard Items (SI) & Operator Items (OI) :

$$OEW = MEW + SI + OI \qquad (4.1)$$

- For any aircraft with a defined MZFW, the maximum payload can be calculated as:

$$Max\ Payload = MZFW - OEW \qquad (4.2)$$

- For any aircraft with a defined MTOW, the maximum MTOW can be calculated as:

$$MTOW = MZFW + Reserve\ Fuel + Trip\ Fuel \qquad (4.3)$$

4.5 AIRCRAFT PAYLOAD-RANGE DIAGRAM

An aircraft weight is usually built-up with respect to the aircraft payload-range diagram. This diagram is useful for operators in two ways: (1) comparing the payload range capabilities of different aircraft types, (2) determining the amount of payload that can be carried on the aircraft and for what distance. The payload-range diagram is affected by many factors, such as: aircraft aerodynamic design, engine technology, fuel capacity, and passenger / cargo capacity. Figure 5.2 illustrates a typical payload-range diagram, and it can be noticed that there is a natural trade-off between the aircraft payload and its range of performance [55].

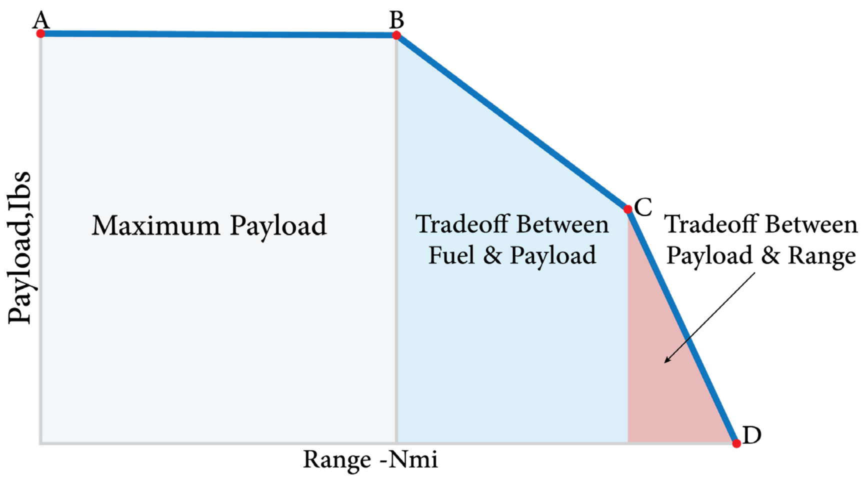

Figure 4.2 Payload-Range Trade-Offs

The curve is divided into three areas, the grey area between "A" & "B" shows the aircraft ability to carry the maximum payload over a specific range, depending on the aircraft type. However, longer ranges are possible to be flown, if and only if, the operator reduces the aircraft payload in exchange for more fuel – as depicted in the blue area between points "B" & "C". Moreover, the trade-off between payload and fuel can continue to point "C", in which, the maximum operational range is achieved with full fuel tanks.

Any item aboard the aircraft is "matter", and any increase in the total weight, is a performance penalty. In fact, much of the weight lifted on the aircraft, is an unavoidable object that makes the flight possible. These unavoidable weights include the aircraft body (airframe, engines & fuel) and crew. Any other weights can be used to transport passengers, baggage and customer - goods. The extra weights on the aircraft are the aircraft load that customers pay for, which represents the origin of the term payload. Note that, the main concern for airline companies, is fuel consumption. In other words, how much (fuel / passenger) an aircraft consumes is the most important issue for the airline board of management.

4.6 BOEING (747 - 100) SPECIFICATIONS AND WEIGHTCALCULATIONS

To find answers for the aforementioned question , simple weight calculations have been implemented on a Boeing 747-100, as an example. It assumed that, this aircraft performs a journey from London Heathrow Airport to Los Angeles Airport which is a distance of 5,440 miles.

4.6.1 BOEING (747- 100) FUEL CALCULATIONS

The basic data for Boeing 747-100 in an airline service, is presented in Table 4.1.

Table 4.1 Boeing 747-100 Specifications[56]

Maximum Fuel Capacity	L 183,380
MTOW	KG 333,390
Empty weight	KG 162,400
Range	KM 8,560

To calculate the weight of the maximum fuel load that has been used, whose fuel type needs to be identified first, then a conversion factor is applied to obtain the fuel weight. The basic common jet fuel is Jet A or Jet A1, with a density, on the ground of about 0.804 Kg / L, [57].

Fuel Weight = Maximum Fuel Capacity × Fuel density**......................................**(4.4)

$$= 183380 \times 0.804$$

$$= 147437 \text{ kg}$$

4.6.2 BOEING 747 -100 WEIGHT AND LOAD CALCULATIONS

To evaluate the weight that can be loaded on the aircraft equation (4.2) has been used to calculate the Maximum Structural Payload (MSP) that includes passengers, baggage, and cargo,Note that Maximum zero fuel weight (MZFW) and the Operating Empty Weight (OEW) need to be defined as:

MSP = MZFW- OEW** ....**(4.2)

= (MTOW- Fuel Weight) - OEW

$$= (333390 - 147437) - 162400$$

$$= 23552 \text{ kg}$$

With further investigations, it can be seen that the 747–100B aircraft with the calculated payload, can perform the dedicated journey, more weight calculations are carried out as shown below:

With a rough estimation for the weights of the standard and operator items, (such as unusable fuel, engine oil, fire extinguishers, galley structures, crew and their baggage, food and beverages, aircraft documents, life rafts & life vests), are to be around 6000 kg. While, for the crew weight, and according to the standard weights of passengers and baggage, the respective average male and female crew weights are 86.64 kg and 74 kg. Then, adding the clothes weight, which is 3.6 kg in summer and 6.4 kg in winter [58]. In addition, taking the male/female distribution in the aircraft as 60/40 for the 16 crews provides a weight of around 1463 kg in summer and 1505 kg in winter. Now, these weights have to be deducted from the MSP. The 747-100B is ready to be loaded with passengers and their luggage with only around 16 tones.

Airlines have different scenarios for seat allocation, for example, a Boeing 747-100 can carry 412 passengers in 2 classes or 266 passengers in 3 classes. However, the first configuration does not work at all with the basic passenger distribution as (220 men, 175 women, and 32 children) even in summertime since their total weight is more than 28 tones.

For the 3 classes configuration, the passenger weight comes down to around 17 tones as (130 men, 110 women, and 26 children). However, this weight is still over the MTOW. Note that this is the passenger's weight only, and without their luggage. Therefore, a Boeing 747-100, with this payload, cannot perform the journey from London to Los Angeles, especially it needs the whole fuel load to perform the journey.

Hence, up to this moment, no mention about the personal baggage weight was made. If it is assumed that each crew member and passenger, had a carry-on bag with an average weight of 7 Kg, this would make the carry-on bags weight on the Boeing 747-100 around 1975 Kg. While for the hold bags, if each of the 200 Economy passengers is allowed one bag at 30 Kg and for first class, each had two bags at 50 Kg, this makes the baggage weight around 12600 Kg. Now, the aircraft is around 16 tones overweight. In addition to this, the aircraft needs to offload around 20000 liters of the fuel to get airborne.

4.6.3 AIRCRAFTS PERFORMANCE ANALYSIS

It is obvious that weight is a crucial element for aircraft performance. In this section, the same procedure of weight calculations for a Boeing 747-100 has been followed to investigate the performance of the 12 most popular aircrafts, their details are outlined in Table 4.2.

Table 4.2 Aircrafts Specifications.

Aircraft type	MTOW [kg]	EW [kg]	Fuel Capacity	Range [nm]
B 747-8F	447696	190962	226118	8000
B773	299370	159570	171170	6015
B738	78245	41413	26020	4000
B739	85130	42493	26030	3200
B 787-8	227930	104099	126206	7355
B752	104350	59350	43490	3900
B763	181437	88469	63200	5975
B762	136078	80286	63220	5076
A320	77000	37230	2430	3078
A380	569000	276800	310000	8207
A333	233000	123000	139090	5670
A 319	75500	35400	24210	3672

For any aircraft, if all the seats are occupied, all baggage allowed is carried, and all fuel tanks are full, the aircraft, will be grossly overloaded. However, many aircrafts are designed in a way that, if maximum range is required, occupants or baggage must be reduced. While, if the maximum load is required, the range that is dictated by the amount of fuel must be reduced. To understand the aircraft performance when removing the baggage weight, a bset of parameters, depicted in Table 4.3 A, has been used on an excel spreadsheet to conclude the 12 aircraft performance as shown in Table 4.3B.

Table 4.3A Input Parameters To Calculate MSP

Person Weight [kg]	79.0	Male
Person Weight [kg]	57.6	Female
Clothing [kg]	6.4	Winter
Clothing [kg]	3.6	Summer
Carry-on bag [kg]	7.0	
Hold Bag [kg]	100.0	First Class
Hold Bag [kg]	30.0	Economy
Fuel Cost [per kg]	0.640	£ (Pounds)
Fuel Density [kg/m3]	0.804	

Crew	**(Cockpit Crew + Flight Attendant)**	**Flight Attendant 1/50**		
Pax Distrbution	49% Male	41% Female	10% Minors	15% 1st Class

Type	No. of Pax
B747-8F	605
B773	550
B738	189
B739	215
B787-8	359
B752	239
B763	299
B762	290
A320	179
A380	853
A333	440
A319	440

Table 4.3 B The Calculation Procedure Of MSP

Aircraft type	Aircraft Parameters Defined				Aircraft Parameters Calculated				People Onboard Defined					Season	Calculated weights of Things Onboard Except Fuel						Positive Numbe is Good
	Max Takeoff Weight	Empty Weight	Max Fuel Capacity		MZFW	Fuel Onboard	Fuel Onboard	Lift Capacity Available		1st Class Pax		Econo-my Pax			Crew Weight	Pax Weight	Carry-On Bags Total	Hold Bags Total	(Supplies, Catering)	Total Weight Except Fuel	
	MTOW [kg]	EW [kg]	Fuel Capacity	Range [nm]	[kg]	Fuel [kg]	Cost [£]	AMSP [kg]	Crew	Males	Females	Males	Females		Crew [kg]	Pax [kg]	Bags [kg]	Bags [kg]	Extra [kg]	Total [kg]	MSP [kg]
B747-8F	447696	190962	226118	8000	265897	181799	144716	74935	14	44	37	247	206	winter	1076	40403	3738	21690	6000	72907	2028
														summer	1037	38908	3738	21690	6000	71373	3562
B773	299370	159570	171170	6015	161749	137621	109549	2179	13	40	33	224	187	winter	999	36626	3388	19630	6000	66643	-64464
														summer	963	35270	3388	19630	6000	65251	-63072
B738	78245	41413	26020	4000	57325	20920	16653	15912	7	14	11	76	64	winter	538	12486	1155	6700	6000	26879	-10967
														summer	518	12024	1155	6700	6000	26397	-10485
B739	85130	42493	26030	3200	64202	20928	16659	21709	6	15	13	87	73	winter	461	14215	1316	7600	6000	29592	-7883
														summer	444	13688	1316	7600	6000	29049	-7340
B787-8	227930	104099	126206	7355	126460	101470	80772	22361	10	27	23	149	125	winter	768	24502	2268	13220	6000	46759	-24398
														summer	740	23595	2268	13220	6000	45824	-23463
B752	104350	59350	43490	3900	69384	34966	27834	10034	9	18	15	100	83	winter	692	16349	1512	8790	6000	33343	-23309
														summer	666	15744	1512	8790	6000	32713	-22679
B763	181437	88469	63200	5975	130624	50813	40448	42155	7	22	19	125	104	winter	538	20426	1890	10970	6000	39824	2332
														summer	518	19670	1890	10970	6000	39048	3107
B762	136078	80286	63220	5076	85249	50829	40461	4963	8	22	18	121	101	winter	615	19828	1834	10660	6000	38937	-33974
														summer	592	19095	1834	10660	6000	38181	-33218
A320	77000	37230	23430	3078	58162	18838	14995	20932	6	14	12	74	62	winter	461	12251	1134	6680	6000	26526	-5594
														summer	444	11798	1134	6680	6000	26056	-5124
A380	569000	276800	310000	8207	319760	249240	198400	42960	20	63	53	354	297	winter	1537	58012	5369	31130	6000	102048	-59088
														summer	1481	55864	5369	31130	6000	99844	-56884
A333	233000	123000	139 090	5670	121172	111828	43466	-1828	11	40	28	226	153	winter	845	34300	3129	18170	6000	62445	-64273
														summer	814	33049	3129	18170	6000	61162	-62990
A 319	75500	35400	24210	3672	56035	19465	15494	20635	5	12	10	63	53	winter	384	10437	966	5680	6000	23467	-2832
														summer	370	10051	966	5680	6000	23067	-2432

From the calculations, it can be observed that only two aircrafts, can perform their whole range of journeys with full payload, they are B747-8F and B763, as shown in Figure 4.3.

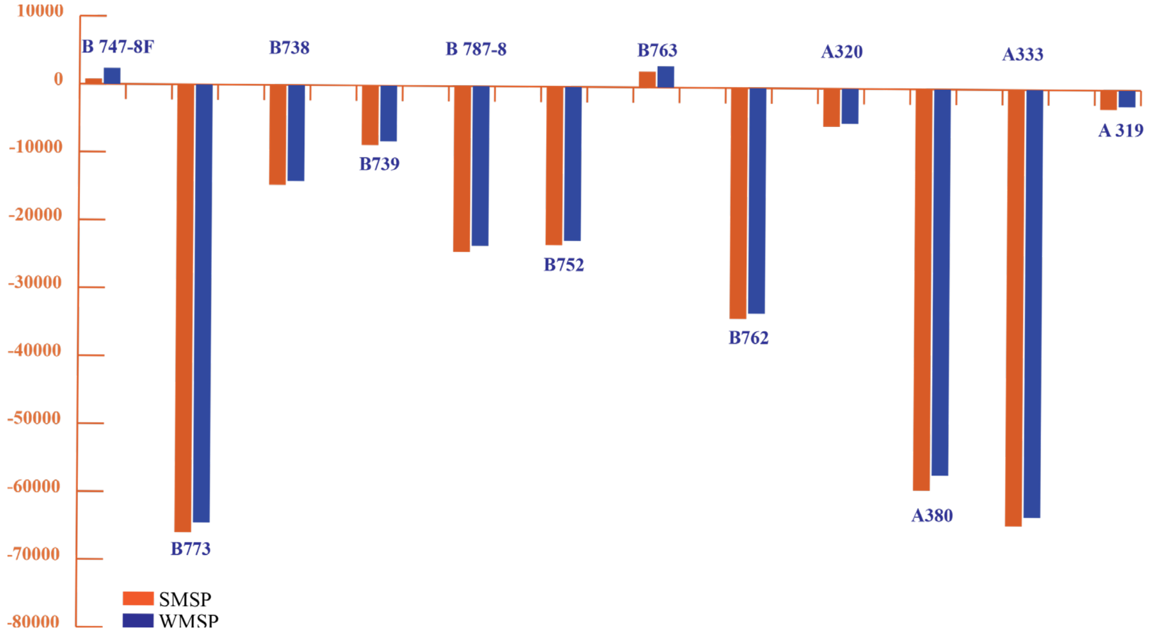

Figure 4.3 MSP vs. Range.

If the luggage weight is deducted from the total MSP, three more aircrafts can perform their journeys. Furthermore, the Airbus 333 can perform its flight during the summer season time, see Figure 4.4 below

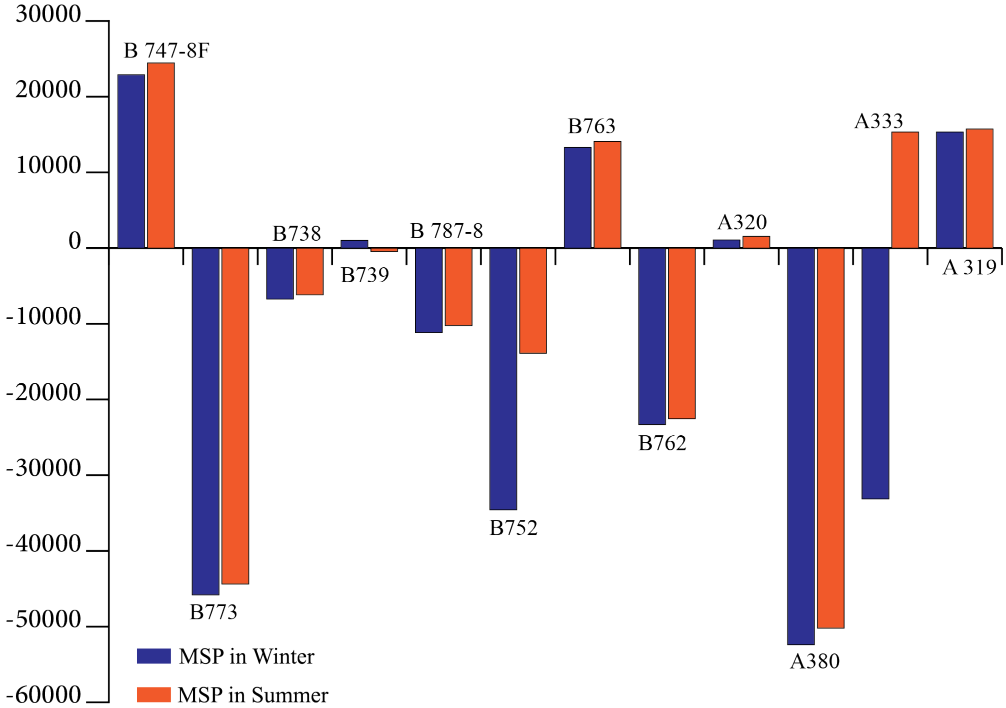

Figure 4.4 MSP vs. Range Without Luggage

In addition, the performance of many aircrafts have been examined to perform a specific journey as an example, to achieve a national direct-flight from London Heathrow (LHR) to Los Angeles (LAX). Noting that the distance between London and Los Angeles is 8750 km the fuel needed to perform this journey has been calculated for the 12 aircrafts depending on the rate of fuel consumed by each aircraft, as shown in Table 4.4.

Table 4.4 Fuel Burn Rate

Aircraft Type	Fuel weight	Fuel burn kg/km	Fuel/8750 km
B 747-8F	181799	10.54	92225
B773	137621	7.88	68950
B738	20920	2.86	25025
B739	20928	3.42	29925
B 787-8	101470	5.11	44712.5
B752	34966	4.16	36400
B763	50813	5.39	47162.5
B762	50829	4.93	43137.5
A320	18838	3.13	27387.5
A380	249240	13.78	120575
A333	111828	6.25	54687.5
A 319	19465	3.37	29487.5

The results of the weight calculation procedure showed that only three aircrafts (B747-8, B763, A380) can perform the flight from London to Los Angeles, as depicted in Figure 4.5.

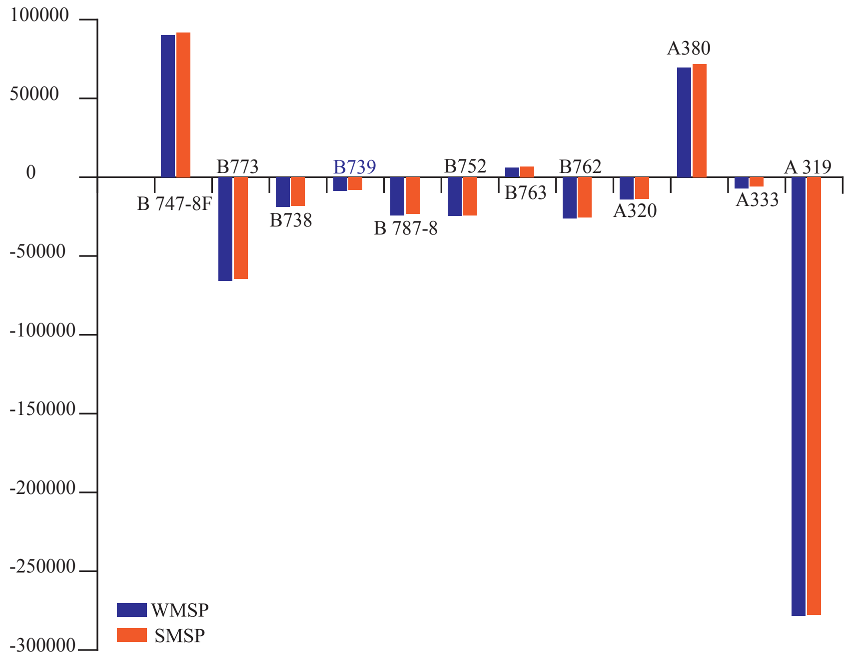

Figure 4.5 MSP vs. Range from London to Los Angeles

However, if the luggage has been removed from the total payload, the A333 can perform the journey as well, as shown in Figure 4.6, even though it has been designed for the Medium-haul flights only.

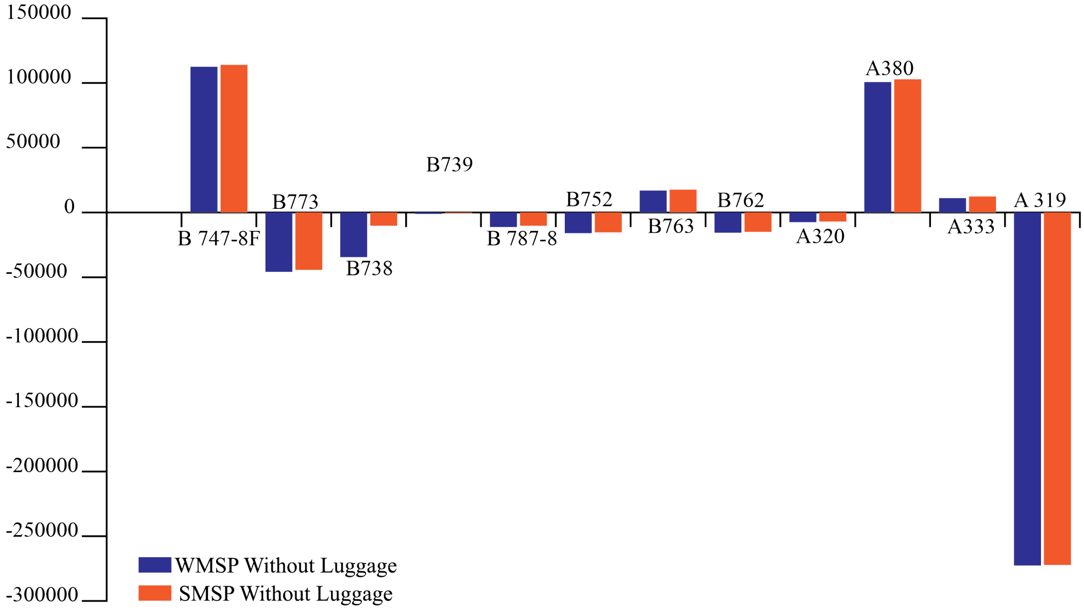

Figure 4.6 MSP VS. Range London to Los Angeles (Without Luggage)

All these results lead to one conclusion, that the baggage weight is crucial, i.e. adding or removing this weight affects the aircraft performance. Somehow, it can make a difference to perform a direct flight, instead of stopping and paying airport charges to load more fuel, to complete the dedicated journey.

4.6.4 DISSOCIATION SCENARIO

It is clear from what has been identified above, that much of the aircraft weight is necessary, and it is an unavoidable part that makes the flight possible. However, if passengers are dissociated from their luggage, the flight is still possible, but may result in better aircraft weight utilization.

Now a simple calculation shows whether this dissociation can make an extra profit than avoiding the transit fees. Suppose that the cargo aircraft B747-8F is used to carry the luggage instead of shipping it with the passengers on the same flight from London - Los Angeles, and in accordance with the specifications that mentioned in Table 4.5.

Table 4.5 Boeing 747-100 Specifications.

Maximum Fuel Capacity	L 226118
Max Payload	Kg 000 140
Max Range	km 7630

The Fuel cost to travel the distance of 8750 km, from London - Los Angeles is:

Total Fuel Cost = 226118 × 0.64 = £144716

The cost of 1 litre of fuel = 0.64 pence (pound sterling) [59].

Thus, if this cargo aircraft has been shared by different airlines to carry their luggage to LA, many scenarios for this sharing, are available. However, the main concept here, is to find whether this dissociation can make extra profit for the airlines or not.

Suppose that these airlines charge £50 for baggage check-in and delivery of 30 kg.

Therefore, for Boeing 747-100:

Luggage cost = £50 x 410

= £21,000

Note that 747-8F can carry the baggage for 11 airlines that use Boeing 747-100 and each airline can collect that £21,000 for the luggage services. The fuel cost will be covered by 11 airlines and £7844 will be left for each airline that can be used to cover the airport charge at the transit stage and cover the cost of delivering the luggage to and from the airport. From these basic calculations, and due to the lack of data, since baggage weights and pricing of baggage delivery services are difficult to obtain, as they are proprietary and not disclosed by the airlines or airports. Until now, the preliminary investigation results showed that dissociation can be beneficial over the long term, for both airlines to make profits and for passengers to improve their experience by making their journey hassle free.

4.6.5 PASSENGERS INCONVENIENCE AND THE POTENTIAL DELAY

For any service that is provided by a supplier, a service-level agreement (SLA) is required, which is defined as a contract between the service provider and the customers that documents what services the provider will furnish and defines the service standards the provider is obligated to meet. SLAs help the service providers to manage customer expectations and define the severity levels and circumstances under which they are not liable for outages or performance issues. From the other hand, customers can also benefit from SLAs because the contract describes the performance characteristics of the service and sets forth the means for redressing service issues. In our case with a baggage delivery service, we can consider several versions of SLAs that can be set between passengers and the airlines or between passengers and the airports depending on who is going to provide the service. Moreover, different SLAs can be set depending on the passenger's type (Business, leisure, male, female, child, etc..). To overcome the potential passenger's frustration regarding the delay of baggage delivery, these SLAs should specify in their terms and conditions what exactly to expect, how to measure it, the penalty for not delivering what was promised. For example, money back, vouchers, discount on future flights, etc. Also, SLA may include insurance, for example, lost luggage, canceled trips, changes to the itinerary etc.

4.7 SUMMARY

In conclusion, weight costs money to carry and fuel to burn, therefore it is a matter for airlines. In this case, baggage weight is a useful extra revenue earner when the dissociation concept is considered. Since, it can be concluded that luggage weight is critically linked to the aircraft capacity and it can make a clear difference if it is offloaded from the aircraft. It has been noticed that between 12 of the most popular aircraft types five of them can make their full-range journey without the need for the transient phase if they fly without luggage, which means airlines can make an extra profit if they avoid the transit phase that requires paying the airport charge fee. Also, they can make extra profit from carrying extra passengers instead of the luggage weight that has been off-loaded.

CHAPTER 5

BAGGAGE GROUND DISTRIBUTION NETWORKS

5.1 INTRODUCTION

In an attempt to manage airport congestion the concept of passenger/baggage dissociation has been proposed, and this project argues that the complete end-to-end dissociation involving the air segment is critically dependent on the dissociation in the ground segment. Therefore, as a prime research objective and inspired by the existing parcel delivery networks, an envisioned network for baggage delivery has been considered here.

In this chapter, an optimization model has been developed for the design of the Baggage Ground Distribution Networks (BGDN) in Greater London as a case study. A maximal covering location problem and p-median location problem are employed to determine the optimal numbers and location of the Baggage Sorting Centers (BSCs).

5.2 THE ERA OF X- AS-A-SERVICE " XAAS "

Recently, new economic models have emerged to exploit increasingly interconnected systems and processes. Similarly, to the basic principles of cloud computing, the underlying idea of an XaaS economic model is to pool and then share the existing infrastructures to deliver services with much better efficiency and flexibility. In the case of Transportation-as-a-Service (TaaS), which is also known as Mobility-as-a-Service (MaaS), the public and private transportation services in urban areas are combined to provide a seamless passenger experience and effective goods delivery service [60]. In Air Transport, the XaaS concept emerged as Baggage-as-a-Service (BaaS), BaaS is currently offered by several large airlines in some urban areas to deliver the luggage of their passengers to the airport. Alternatively, the baggage is delivered directly to their premises if the baggage is delayed and it did not arrive at the destination airport on the same flight as the passengers. However, this is rather a small-scale service, which is not comparable with the scales expected from the BaaS. In addition, the main difference between BaaS and the baggage dissociation concept is that the former currently narrows down its focus on the dissociation in the ground segment only and is usually for selected type of passengers whereas this project reasoning is about the baggage dissociation in more general and widespread large scale adoption, and more importantly, it embraces the air segment dissociation.

The complete dissociation of passengers and their baggage would raise the BaaS concept to a new level. In fact, the complete dissociation may change the notion of baggage as it is understood today. When baggage is delivered end-to-end independently from the travel of the passengers, such baggage delivery becomes akin to parcel delivery. Parcel delivery services are now well established as they have evolved over a number of past decades [61]. Some of the main problems considered in optimizing parcel delivery services is choosing the locations of hubs, distribution and sorting centers, and scheduling delivery vehicles and their routes, especially in the last-mile delivery. Following the MaaS concepts, the traditional logistics networks are extended to support online retailing [62]. Consequently, it is natural to consider traditional parcel delivery networks as well as logistic networks for goods delivery to also support baggage delivery. In fact, it is unlikely that airlines and airports have enough resources to build completely new baggage distribution networks. Rather, they can exploit existing infrastructures and focus on upgrading the existing parcel delivery services to comply with the requirements and needs of the air transport industry. This may even eventually lead to complete outsourcing of baggage delivery services to 3rd party providers while air transport companies would treat baggage as cargo.

5.3 BAGGAGE DISSOCIATION IN AIR & GROUND SEGMENTS

The baggage/passenger dissociation concept was presented in detail in chapter one, however to further our analysis, there is another line of reasoning about baggage dissociation, which needs to be considered here to answer the third research question (which to consider first, dissociation in the air segment or dissociation in the ground segment). In particular, the initial step may be to consider baggage dissociation in the air segment as the primary objective. Thus, when passengers arrive at the airport with their luggage, they are put on different flights. Since passengers and their luggage are likely to arrive the destination airport at different times, it significantly complicates luggage reconciliation. This may require either sufficient luggage storage capacity at the airport (i.e., the luggage arrives the airport before passengers) or to move the reconciliation off the airport to the passenger's final destination in order to avoid the passengers waiting time at the airport. The latter resolves both these scenarios, so the off-airport luggage distribution is an inevitable consequence of air segment dissociation. Once the luggage distribution is offered at the destination airport, it is sensible to offer a similar service for the luggage collection at the departing airport. Hence, dissociation in the air segment is conditioned on the baggage dissociation in the ground segments. Therefore, the implementation challenges of the ground segments need to be addressed first.

5.4 GROUND DISTRIBUTION NETWORKS FOR BAGGAGE

Many distribution networks share common problems and design issues. In particular, the delivery capacity is limited which can create congestion. Congestion is perceived by service users as a sudden and significant delay in the service being provided. Improving the network management to better utilize the available capacity and resources, for example, to suppress the congestion problem, increases the network complexity which in turn reduces its resilience to unpredictable disruptive events. The reduced resilience then raises new security issues, and the service disruption has larger and more profound economic and social consequences. The scalability issue provides last-mile service provisioning at the network edges. Although it is relatively easy to add additional nodes to the network at the edges, increasing the hub capacity to support the added nodes is much more difficult. On the other hand, providing the network services in areas with a high density of users is economically much more viable than in other less populated areas. In addition, the transport capacity of many networks is not constant, but it may vary significantly over the course of the day. The time varying capacity can be exploited by scheduling the delivery to later times if such delay can be tolerated. There may also be instances when a delivery is misplaced or lost.

It is important to note that even though many of these issues have been somewhat mitigated to various extents by the use of the digital technologies and the Internet, the physical laws limiting the performance of the services, in general distribution networks are unavoidable by any means. Assuming the ground distribution networks for baggage delivery to and from the airports as the main focus of this project, first a review of the parcel delivery networks which are used extensively within the national economies has been presented. Then it reuses the same design principles of these networks to devise a network topology for the baggage delivery networks. Parcel delivery networks have a strictly hierarchical topology [60]. The consolidation centers or points (CP) and distribution stations (DS) are required for achieving the delivery efficiency of the delivery vehicles, and they are located within the distribution or delivery center that is also known as last-mile sub-networks. The sorting centers (SC) act as gateways for the parcel delivery to and from the distribution centers. The sorting centers are interconnected via a network of long-haul transportation links and hubs. Interestingly, whereas the last-mile subnetworks are in operation during the whole day from early morning until late evening, the long-haul transportation networks to deliver parcels between the distribution centers are normally exploited mainly overnight. The parcel delivery networks are usually designed in at least two subsequent steps. In the first step, the decision is made on the number and location of the network hubs (sorting centers and distribution stations). The parcel flows are then optimized in the second step. The parcel service in a typical country in Western Europe relies on 10's of sorting centers, 100's of delivery stations and 1000's of delivery vehicles in order to obtain the capacity of 100's of millions of parcels delivered per year. Fortunately, the formulated optimization problems are usually linear, so they can be solved efficiently even in such large scales. The optimization problems are parameterized by a large number of variables and constrained by a number of limitations and requirements. These include the number and size of the vehicles and their availability, the type and nature of the customer demands and whether they can be predicted, the throughput of roads, and the constrained are usually related to various fixed and variable costs. The objectives of these optimizations can be easily conflicting, giving rise to various trade-offs. For instance, minimizing the service costs is usually possible at the expense of the service quality such as the delivery delay. These high-level objectives then translate to more specific requirements such as the required number of vehicles, the total distance traveled during the delivery, and the number of customers that have been visited.

5.5 POSTAL NETWORK DESIGN

A typical distribution network for letters or parcels can be explained by the following subnetworks:

- Mail collection sub-network: This network is responsible for collecting mail whatever, parcels or letters, from different mail sources such as business customers, mailboxes and then transports it to sorting centres. Consolidation points (CoP) are used to switch from small to bigger vehicles, which then transport the mail to the corresponding sorting centres.

- Sorting centres (SC): These big automated sorting facilities work in two different modes at different time intervals. The input sorting centre (ISC) performs the sorting process with respect to the destination sorting centre (SC) while the output sorting centre (OSC) performs sorting for both distribution and delivery to the final destination.

- Long-haul transportation subnetwork: This subnetwork takes care of the mail exchange between the sorting centres (overnight). The main idea is to use bigger and faster vehicles for long distance transportation and to consolidate the mail at a subset of sorting centres, which they use as hubs. In real world applications, the long-haul transportation sub-network is often implemented in two different transportation modes, road–rail or air–road.

- Distribution sub-network: In this sub-network, the transportation is responsible for distributing the mail using vehicle routes from the sorting centres to mini-hubs which are defined as delivery stations (DS) if the mail is a letter or delivery bases (DB) if the mail is parcel. At these mini hubs, a final sorting process in sequence takes place for each of the assigned delivery districts (DD).

- Delivery (last mile) sub-network: Each postal worker has an allocated delivery district, in which the delivery route starts at the mini hub, moving to the delivery district. The postal worker visits the delivery district in a predefined (optimal) sequence and finally return to the mini hubs (DS/DB).

5.6 BAGGAGE DISTRIBUTION NETWORKS

The proposed baggage delivery network, that is inspired by the parcel delivery network is depicted in Figure 5.1. This network requires the use of the existing baggage handling systems (BHS) at the airport. The structure of the baggage distribution network requires at least two-tier topology. The BHS at airports will perform the first level sorting of the arriving baggage towards the appropriate baggage sorting centers (BSC) that are located outside the airport. It is supposed that these BSCs are shared among multiple airports and perform second level sorting. Also, these BSCs may also provide longer-term storage of baggage which would not otherwise be available at the BHS. Note that no baggage is routed directly between BHS, but always through BSCs. Thus, baggage to other cities would be routed via the BSC sub-network. We consider that these BSCs feed directly to the second tier which are the local baggage delivery stations (BDS) for the last mile delivery. The links between BHS and BSC, between different BSC, and between BSC and BDS are assumed to have large transport capacity, for example, they can be realized as dedicated high-speed train or trucks delivery links. The BSCs are distributed throughout the city to provide the service coverage of the whole area. Note that the BDSs are connected only via the BSC, but not directly. The end-to-end baggage delivery service also requires defining the admissible end-points such as homes, local shopping malls and stores, post offices and hotels [66].

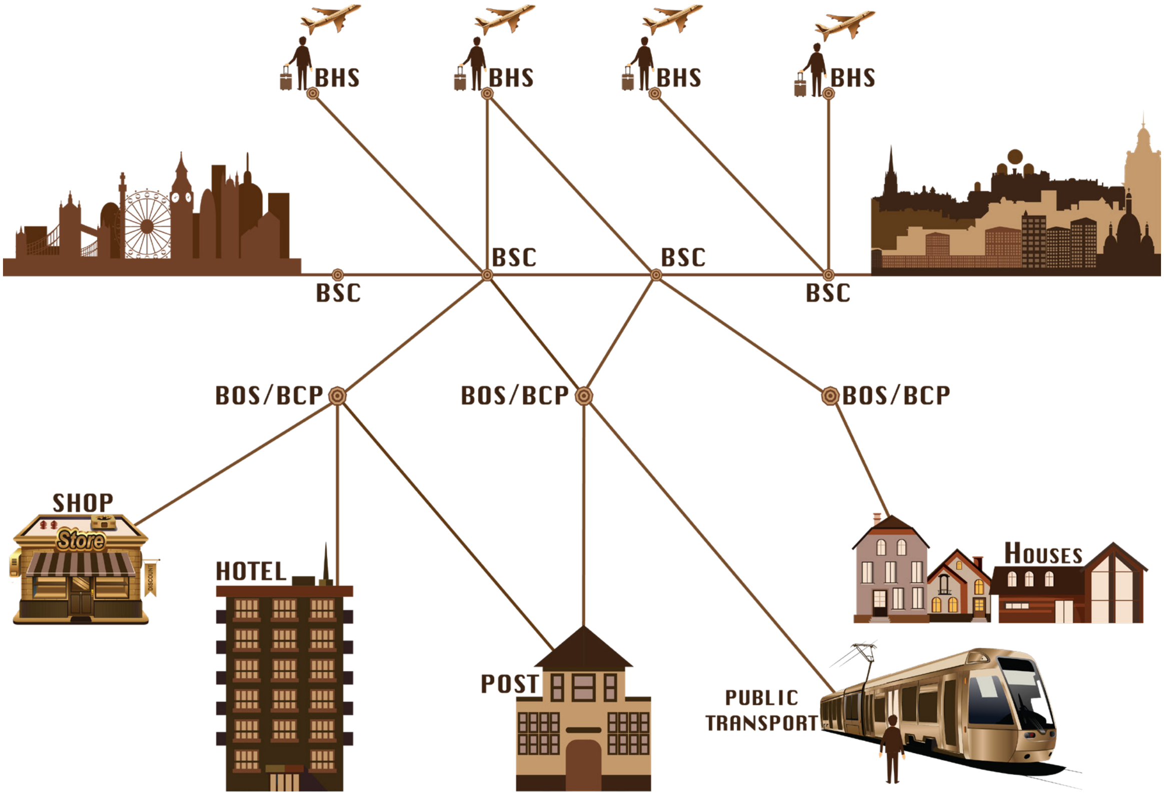

Figure 5.1. Sample topology of the baggage collection and distribution network

5.7 PROBLEM DEFINITION

As has been previously mentioned in Chapter Two, many airports have congestion problems. The European Observatory on Airport Capacity & Quality report stated that European airports expected demand to increase from 9.4 million in 2011 up to 25 million in 2050 and this growth will force some of the airports to operate at their full capacity. According to the statistics, by 2035 more than 20 airports will be at their capacity limit compared to just three in 2012 [64]. The problem is the airports cannot grow at the same pace to meet this rate of increasing demand since every airport can only manage a finite number of aircrafts and passengers at a time. This limitation can be the result of the physical constraints such as the maximum number of flights that the airport's runway can accommodate and/or for regulatory constraints such as specific number of flights allowed after a certain hour at the evening time [65].

This capacity limitation makes both airlines and passengers suffer from congestion during peak travel periods, Figure 5.2 shows this variation for the arrival passengers to London airports as an example of Gatwick Airport. The arrivals varied in the busiest day from only 156 passengers to 10,099 passengers. These busy hours can create long queues before the check-in points, the baggage drop-off points, which can form a stress point for passengers and prevents the seamless airport experience. Due to these bottlenecks, and long waiting times, passengers might miss their flight and at the same time costly delays will be generated.

Globally, with the rise to more than 4 billion travelers and more than 4.27 billion bags checked-in in 2108 a considerable pressure has been put on the industry's baggage systems [66]. As mentioned earlier one of the proposed solutions that may relieve this pressure is free baggage travel, and as a first step to implement this concept, the allocation of baggage sorting centers (BSC) using an optimization model for Greater London has been considered.

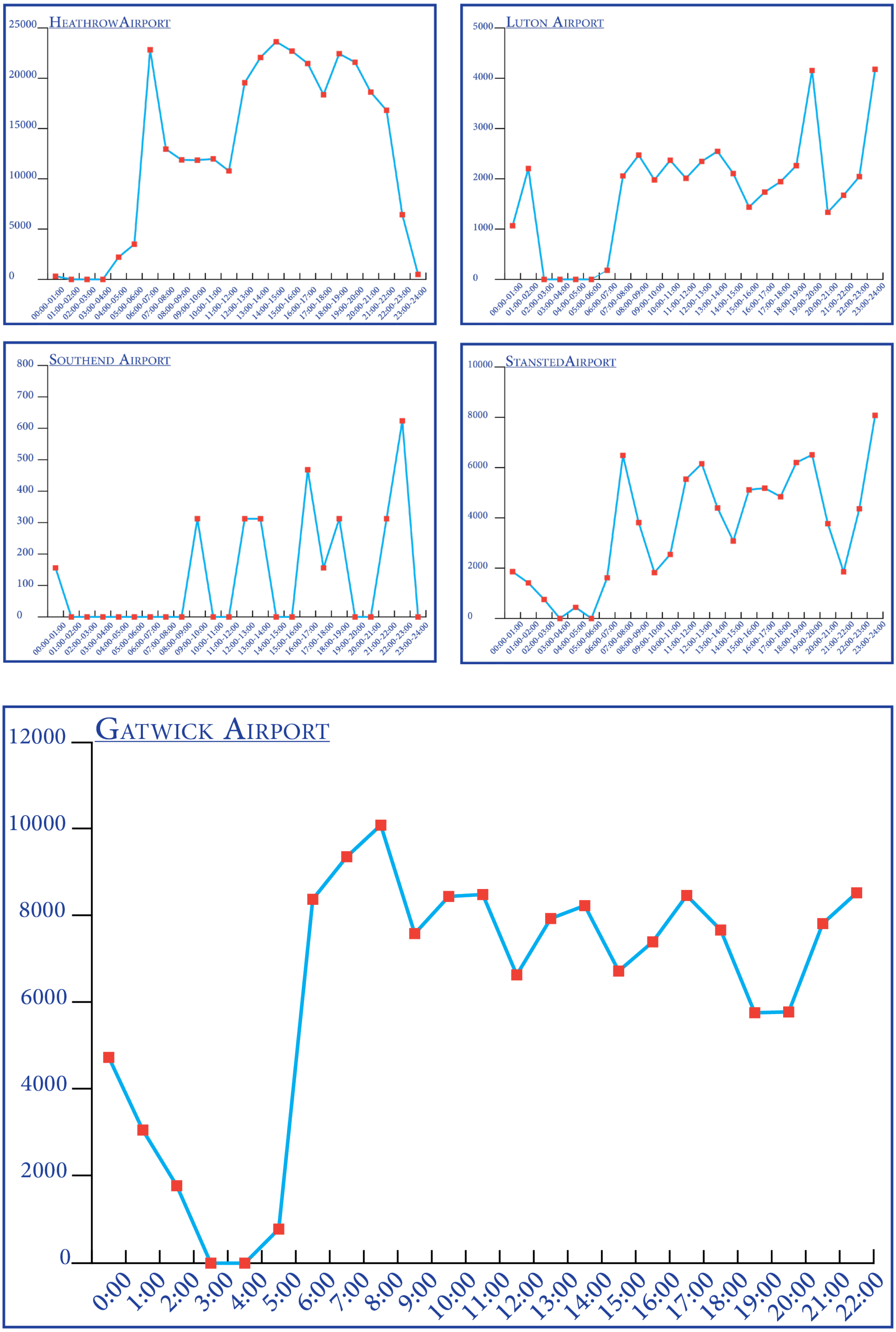

Figure 5.2 Variation Of The Arrival Passengers To London Airports During Buiest Day.

5.7.1 LOGISTICS MANAGEMENT

Logistics, is defined by the Council of Logistics Management, as "that part of supply chain process that plans, implements and controls the efficient, effective flow and storage of goods, services, and related information from the point of origin to the point of consumption in order to meet customers' requirements." Therefore, facility location and demand allocation are the most important factors in the design and management of a logistics system. The location of the facility and allocation of customers to that facility determine the distribution pattern and the associated characteristics, i.e., cost, time and efficiency of the distribution pattern. Therefore, the optimal placement of facilities and assignment of customers, cannot only improve the flow of services that are offered by the facilities, but also utilize them in an optimum manner [66].

Facility location and allocation problems are two-stage decision-making. The first stage decisions are to establish the logistical network by choosing the optimal facility locations from some known feasible locations (discrete location problem) or from an infinite number of locations described as an area/ coordinates for a location (continuous location problem). In the second stage, the customers are assigned to respective facility or (facilities) in a way that the total operating cost of the logistical network is minimized. However, what is the facility, and who is the customer, these terms will be defined depending on the nature of the problem. In this project, the facilities are the baggage sorting centers, while the customers are the passengers segmented based on their geographic locations.

5.7.2 CLASSICAL MODELS OF FACILITY LOCATIONS

A Facility location problem has proven to be the fertile ground for operations researchers who are interested in algorithm development, complexity theory, and modelling. The location modelling applications include locating schools, hospitals, emergency medical service, fire stations, airline hubs, warehouses and waste disposal sites to specify only a small subset of the wide numerous areas in which the location models have to be applied.

Most of the location problems can be defined according to the following factors: given space, number of customers, distance, demands and mission. In which, the distance is known between any two points in that given space. The number of customers is located in that space under consideration and who they have a certain demand for the service (or product). While, the mission is locating one or more facilities in that space that will satisfy some or all the demands.

Usually, facility location problems are characterized by the following essential elements [67]:

- Space for the facilities to be located.
- Facilities (already new and exciting) to be located.
- Customers to express the service demand.
- Customers and facilities interaction.
- Metrics to measure the distances between facilities and customers.
- The Constraints to be satisfied.

5.8 LOCATION MODELS CATEGORIES

According to Hakimi, there are four possible categories for the location models that can be used to represent a problem[68]:

- Analytic models: in this case are a lot of simplification assumptions, such as the uniform distribution of certain demands or the same cost for fixing facility in each position.
- Continuous models: here the facilities can be located in each point of the continuous space, while demand is concentrated in points.
- Network models: the customers and facilities are located on a network. Typically, demand is associated to nodes, where cost is associated to the links that connect to the demand points.
- Discrete models: there are a discrete set of the demand points, as well as a discrete set of candidate potential locations.

Usually these kind of problems formulated as integer-programming problems or mixed integer-programming problems. In nature, the baggage distribution network design problem can be considered as a discrete location problem of service facilities, therefore a brief overview of the discrete facility location problems is presented in the next section.

5.9 BASIC DISCRETE FACILITY LOCATION PROBLEMS

In this section, the most used mathematical models for facility location problems has been provided. For the models that are defined in the discrete location space usually, they have a set of demand points with an associated weight as well as a set of facility locations that are the potential position of the location of the new facilities.

5.9.1 THE *P*-MEDIAN PROBLEM

The goal of the p-median model is minimize the weighted sum of the distances between a set of demand points and *p* facilities to be opened. *P*-median model first proposed in 1960's by S. L. HAKIMI to find the optimum distribution of *p* switching centre in a communication network and to assign the minimum number of policemen in a highway network [69] [70]. Since then many versions of this model have been defined in the literature, and it was used in many various applications such as the location of warehouses, industrial plants and public facilities for more examples see [71]. In the *p*-median model there is the significant assumption which is the number of *p* facilities should be located exactly while the another important assumption is the customers will be located to the most close facility. *p*-median mathematical model can be formulated as follows:

$$\sum_{j \in J}^{n} \sum_{i \in I}^{n} h_i d_{ij} \ y_{ij} \text{...}(5.1)$$

$$\sum_{j \in J} Y_{ij} = 1 \ \forall_i \le I \text{...}(5.2)$$

$$\sum_{j \in J} x_j = p \text{..}(5.3)$$

$$Y_{ij} \le x_j \forall_i \in I; \ \text{j} \in J \text{...}(5.4)$$

$$X_j = \{0,1\} \ \forall \in J \text{..}(5.5)$$

$$Y_{ij} = \{0,1\} \ \forall \in I ; \in J \text{..}(5.6)$$

$$0 \le Y_{ij} \le 1 \ \forall_i \in I ; \in J \text{...}(5.7)$$

n = Total number of demand points.

$\boldsymbol{h_i}$ = Demand at point *i*.

$\boldsymbol{d_{ij}}$ = Travel distance between customer point i and candidate location *j*.

$\boldsymbol{Y_{ij}}$ = 1, if demand node I is assigned to a facility at candidate location *j* = 0, otherwise

$\boldsymbol{x_j}$ = 1, if facility is located at candidate location *j* = 0, otherwise

p = Number of facility to be located.

In this model, the objective of equation (5.1) is to minimize the demand-weighted total distance between service facilities and demand sites. While constraints (5.2) ensure that all the demand nodes are assigned, constraints (5.3) ensures that there are p facilities that are going to be located. Constraints (5.4) guarantees assignment to open or selected sites. Constraints (5.5) and (5.6) make sure that all variables are binary.

5.9.2 THE *P*-CENTRE LOCATION PROBLEM

The *p*-centre problem seeks the location of *p* facilities, in which each demand point receives the service from the nearest facility. The objective is to minimize the maximum distance for all demand points. The difference between this model and the previous class is that the maximum distance between the demand point and the nearest facility is as small as possible instead of minimizing the total distance between demand points and the facility. Basing on D is the maximum distance between a demand node and its nearest facility, and by using the same variables of *p*-median the problem will be formalized as follows [69]:

Min D s.t.

$$\sum_{j \in J} Yx_{ij} = 1 \forall_1 \leq I \quad \text{(5.8)}$$

$$X_{ij} \leq y_i \forall_i \in I \ ; j \in J \ ; i \neq j \quad \text{(5.9)}$$

$$\sum_{i \in J} y_i = p \quad \text{(5.10)}$$

$$D \geq \sum_{j \in J} d_{ij} x_{ij} \forall_i \leq I \quad \text{(5.11)}$$

$$X_{ij} \in \{0,1\} \forall_i \in I ; j \in J \quad \text{(5.12)}$$

The objective function is to minimize the maximum distance between any demand node and its nearest facility. Constraints (5.8) to (5.10) are similar to (5.1) to (5.3) of the p-median problem. While constraint (5.11) specifies the maximal distance between any demand node i and its nearest facility j. The last constraints (5.12) are the binary constraints to make sure that all the variables are binary.

If the required number of the facilities that need to be located is one, the problem will be called ‘Absolute center Problems’ [69]. In some cases at each demand point there is also associated weight so the objective function will become [71]:

$$D \geq h_i \sum_{j \in J} d_{ij} x_{ij} \forall_i \in I \quad (5.13)$$

Many applications can be described using center models, for example assigning the location of emergency services such as fire stations, hospitals, and for public facilities such as bus stops, parks. Also, this model can be applied in computer network services such as the location of the data files.

5.9.3 MAXIMAL COVERAGE LOCATION PROBLEM (MCLP)

One of the basic objectives in the location modeling is “coverage” which used to ensure that each customer is “covered” in another word is served by a certain facility if the distance between them is less than a certain threshold, or a required distance. This model has been proposed by Church and ReVelle ,and it has been initially developed to determine a set of facility locations that would maximize the total demand that serviced by these facilities within a pre-specified maximum service distance [72]. Usually, this model can be directly applied for most of the facility-location problems, such as the location planning for healthcare centres, warehouses, fire stations, libraries, etc.

The development of the maximal covering location problem (MCLP) can be traced back to the classical p -median problem. It seeks the maximum population that can be served within a stated service distance or time given a limited number of facilities. The mathematical formulation of this problem can be defined using the following notations: i, I are the indices and the set of demand nodes, respectively; j,J are the indices and the set of potential facility locations, respectively; Ni = $\{ j \in J \mid d_{ij} \leq S \}$ is the set of potential facility locations covering the node i within a distance or time S; d_{ij} is the distance between the potential location of facility j and the node i . The design is governed by the following input parameters: p is the number of facilities which are to be located; S is the maximum allowed distance or time to respond to the requests; and w_i represents the demand at node i .

The decision variables are:

$$X_i = \begin{cases} 1, \text{Facility is located at Node j} \\ 0, \text{Otherwise} \end{cases} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots(5.14)$$

$$Y_i = \begin{cases} 1, \text{Node i is coverd} \\ 0, \text{Otherwise} \end{cases} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots(5.15)$$

Note that the node i is covered, i.e., $y_i = 1$ if $\exists \mathbf{j}$: $xj = 1$ and $j \in N_i$. The optimization problem to solve is then defined as:

$$Max\ \ Z = \sum_{i \in I} x_i y_i \ \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots(5.16)$$

$$\sum_{j \in N_i} x_j \geq y_i, \forall_i \in I \ \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots(5.17)$$

Subject to:

$$\sum_{i \in N_i} x_i = p \ \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots(5.18)$$

$$x_i \in \{0,1\}, \forall_j \in J \ \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots(5.19)$$

$$y_i \in \{0,1\}, \forall_j \in J \ \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots(5.20)$$

The objective of this model is to maximize the demand that covered by the set of the established facilities (5.16). Constraint (5.17) shows that one or more facilities will be located within the distance or travel time pre-defined S from the demand node *i*. Constraint (5.18) rules that the number of facilities to be located is exactly *p*. Finally, decision variables x_i and y_i are binaries.

5.10 SOFTWARE INTRODUCTION

OpenSolver is the software that has been applied in this model , it is an add-in function that extends Excel's Solver with more powerful linear solver function that is suitable to handle both linear and mixed integer programming models. OpenSolver provides the following features:

- It is compatible with spreadsheet models that built with Excel's Solver.
- It has no artificial limits on problem size.
- It is free, open source software licensed under the CPL.
- Recent versions also offer NOMAD, a nonlinear optimization engine.
- Built-in model visualizer that highlights the model's decision variables, objective and constraints directly on the spreadsheet .
- QuickSolve mode for fast re-solving after making right-hand side changes .
- An auto model feature that analyses the spreadsheet layout and then fills in the Solver dialog automatically.

5.11 THE OPENSOLVER INTERFACE

The OpenSolver commands appear on the Excel's Data tab, as shown in Figure 5.4. This addition to the ribbon becomes visible after double-clicking on OpenSolver.xlam.

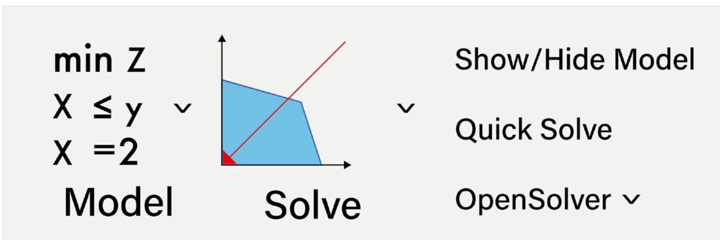

Figure 5.4 The OpenSolver group on the Data tab

For the calculation purposes, the model will be built using Excel's Solver, with setting the objective function, the variables, and the constraints. Once the model is built, the Show/Hide Model button enables the model to be checked and by clicking the Solve button on the ribbon the model will be solved. OpenSolver analyses the spreadsheet to extract the optimization model, which is then written to a file and passed (over the Internet) to the CBC engine to solve. The result is automatically loaded back into the spreadsheet. A dialog is shown only if errors occur.

After solving, OpenSolver does a quick check for linearity in the sense that the objective and constraints behave as expected when the optimal solution is loaded into the sheet. If not, OpenSolver shows an alert, and can then do a detailed linearity analysis.

5.12 A CASE STUDY OF MAXIMAL COVERING LOCATION PROBLEM

A real-world case study has been proposed in this chapter in order to present a deep inside of the location-based modelling approach. The objective is to perform a location-based analysis that required to maximize the demand coverage through the whole baggage network and allocating the maximum number of the BSCs that are needed to cover Greater London area.

5.12.1 CASE DESCRIPTION

Several BSCs are going to be opened in the Greater London area for serving passengers, and the city map is represented in Figure 5.5, which illustrates 173 grids from 1 to 173 are picked in this Figure as a potential location for the BSC. Due to economic reasons, the required BSCs opened should be as few as possible without losing too much coverage of the customer demands. A coverage distance is also needed to be considered in this case.

5.12.2 GREATER LONDON OVERVIEW

London is the largest city not only in the United Kingdom but in the European Union with a population of 9,006,352 in 2018 [73]. It is the largest aviation hub in the world, with six international airports recording 177 million passengers in 2018. Annually around 53 million pieces of luggage are processed at Heathrow airport only and corresponding to the current statistics these numbers are continuing to increase. Therefore this congested city has been considered in this study

5.12.3 CITY MAP ANALYSIS

Before applying the mathematical model, a study of the Greater London area is required to extract some valuable information for the mathematical model. The Greater London map is divided into 33 boroughs (small cities), including the city of London, and by using ArcGIS software the map has been divided into 111 cells depending on the value of the mean area of London boroughs as shown in Figure 5.5. However, this division was not acceptable for economic reasons since the covering value kept changing every time that the p-value was increased (BSCs needing to be opened) as shown in Table 5.1. This point will be explained in detail in section 5.14.1 .

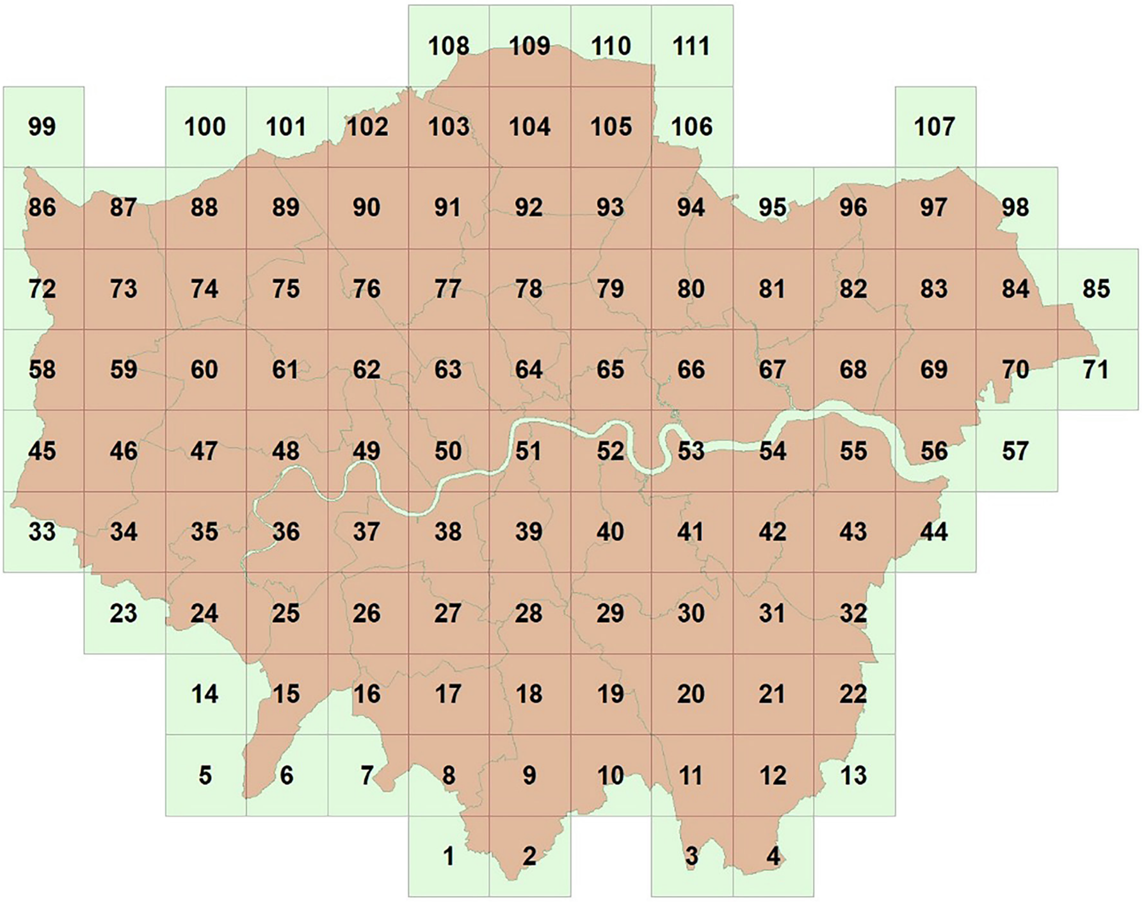

Figure 5.5 Map of Greater London Contains 111 Cells.

Table 5.1 Relationship BetweenWwanted BSC Numbers And Covering In MCLP Under The Condition Of ds Less Than Or Equal To One-Unit Distance.

P	COVERING	P	COVERING
12	12910752	55	33392810
15	15157946	60	34744498
20	18485674	65	35928707
25	21250367	70	36881072
30	23756273	75	37649891
35	26173665	80	38178770
40	28288906	83	38387532
45	30219146	85	38387532
50	31885429		

Therefore, a new division was made using ArcGIS and this time the division was done based on the value of the standard deviation of the area for the 33 boroughs, a new map with 173 cells was used. The plotting scale for this map is 7.5 km and the cells are exactly the same size [LxH] = [5500x5500] as shown in Figure 5.6.

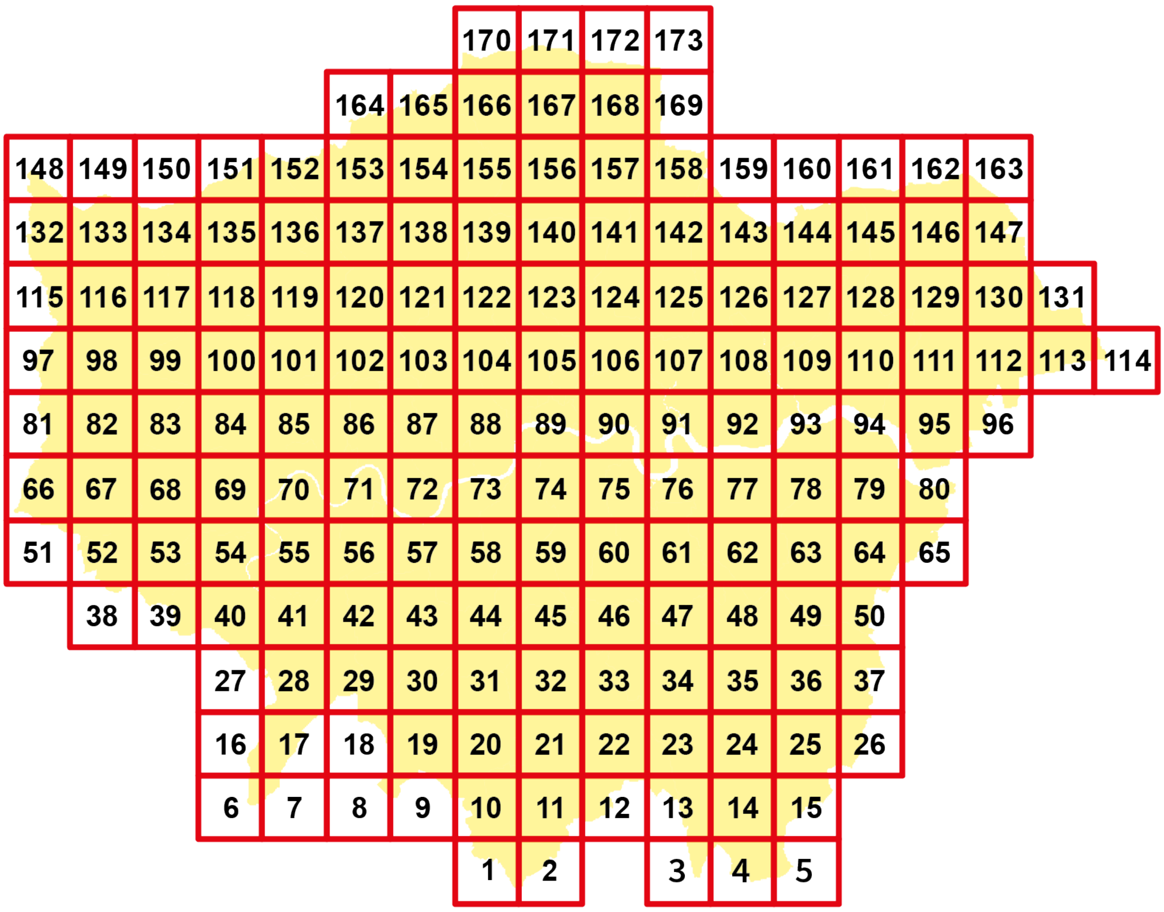

Figure 5.6 Map of Greater London Contains 173 Cells

Thus, the total length of the map on A4 is 9.8 cm and the height is 11.2 cm. Assuming that the coordinates of the left bottom point is (0, 0), then center point of cell 1 is (5.5, 0.37), cell 2 (6.2, 0.37) and cell 10 (5.5,1.1). The reason for calculating the coordinates for all 173 cells at the center point is these points are always dense.

To obtain the distance matrix, Manhattan measuring method has been applied. Manhattan refers to the distance between two points measured along axes at right angles and is applied widely in transportation research. To measure the distance between two points p1 at (x1, y1) and p2 at (x2, y2), is |x1 - x2| + |y1 - y2|. The Python script that is used to calculate the distance matrix as follows:

```
mport pandas as pd
import openpyxl
import math
data = pd.read_csv('Corrected points.csv')
data1 = pd.read_csv('Corrected points2.csv')
x1 = data.iloc[:, :-1].values  # get the frist colume
y1 = data.iloc[:, -1].values  # get the second colume
x2 = data1.iloc[:, :-1].values  # get the frist colume
y2 = data1.iloc[:, -1].values  # get the second colume
i = 0
j = 0
b = openpyxl.Workbook()  # open workbook named "wb" to make an excel
sheet
sheet1 = wb.active  # make a excel file named "sheet1"
sheet1.column_dimensions.width = 174  # change the dimensions of the
width to 174 "becouse the defult width is so small
# start to calculate
for j in range(1, 174):

    # git the first point to calculate
    p1 = [x2[j - 1], y2[j - 1]]  # start in sheet from "j-1" to start
from 0 not 1 "to get the frist value
    for i in range(1, 174):

        p2 = [x1[i - 1], y1[i - 1]]  # git the next point
        distance = float(abs(p1[0] - p2[0]) + abs(p1[1] - p2[1]))
        sheet1.cell(row=j, column=i).value = distance
        print(distance)

wb.save('sheet.csv')  # save the workbook in ecxel sheet and name the
sheet by 'sheet.csv'
```

The demand matrix is presented in Appendix F and it has been produced depending on the population density of each cell, that is calculated using ArcGIS software and the data for this process was collected from LONDON DATASTORE [74].

5.13 BRIEF REVIEW OF THE MAXIMAL COVERING LOCATION PROBLEM

Assuming there is a set of n elements that represented by i ={1,2,3,4…n}, and a set of j subsets of i that represented by j={s1,s2,s3…sm}, the mathematical model of the maximal covering location problem has been formulated between (5.17) and (5.20). The objective of using this mathematical model in this case study is to maximize the coverage of passenger demands within a limited number of BSCs.

ASSUMPTIONS AND PARAMETERS

The model has been formulated as follows:

4. The customer demand is proportional to the population. The customer demand of each grid can be aggregated to its geographical centre. Hence, the customer demand of each grid can be estimated based on the analysis of the population density of each grid.

5. Set of customers and candidate locations are aggregated and represented by the grids, which mean we have 173 customer zones and 173 candidate locations for BSC.

6. Set of locations where the demand from customer *i* can be covered.

To generate the coverage matrix, it is assumed that coverage of a BSC is preferable within a unit distance (length/width of each grid). If the distance between a BSC and the customer zone is less than or equal to one-unit distance, the demand of the customer zone can be covered by the BSC. For example, if a BSC in zone 123 is opened, the demand from itself and the adjacent customer zones 122, 124, 105 and 140 can be covered (The distance from the geographical centers of those customer zones to the geographical center of the zone 123 is equal to one-unit distance). After the parameters have been determined, the MCLP is coded and solved using openSolver and the objective maximizing the coverage demands with a limited number of BSCs to be opened is realized. Different network configurations have been tested with 12 BSCs, 24 BSCs, 36 BSCs,48 BSCs, 60 BSCs ,72BSCs.

5.14 THE MATHEMATICAL MODEL EXPERIMENTATION ON SPREADSHEET

According to the model description the experimentation on the spreadsheet is performed based on the mathematical model of MCLP that is explained in section 6.9.3. Matrixes have been calculated corresponding to the objective function of MCLP model in equation (5.16). Note that SUMPRODUCT function deals only with arrays that have the same size, the demand W_i[nx1] has been expended to matrix W_i[nxn]. The maximal coverage distance ds also need to be set in maximal covering location problem. In this case If the distance between a BSC and the customer zone is less than or equal to one-unit distance the value of S_{ij} equal to 1 otherwise $S_{ij} = 0$. In addition, matrix X_{ij} is the decision variables matrix. Constrains setting in solver function are shown in Figure 5.7 and the number of the BSCs can be set by changing MR185 in the solver parameters setting.

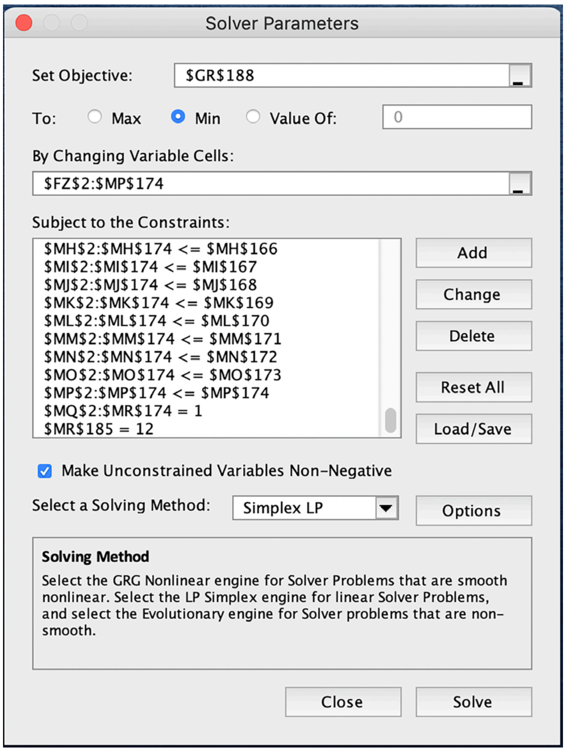

Figure 5.7 Solver parameters setting of MCLP

5.14.1 RESULTS ANALYSIS

The objective is to maximize the demand coverage through the whole baggage network, and investigate the overall requirements to implement the innovative Baggage Distribution Networks. This has been tested based on a suggestion that the required number of the BSCs that need to be opened is 12 then this number was doubled in each test . With keeping the maximal coverage equal to 1-unit distance, the outcomes with respect to different number of wanted BSCs are presented as follows:

Table 5.2 Relationship Between Wanted BSC Numbers And The Coverage Under The Condition That ds = 1-Unit Distance In MCLP Model.

Number of Wanted BSC	Locations	Covering	Covering Rate =Weight Cover-ing / Total Demand (8160634)
12	21,44,60,77,84,89,102,122,128,136,156.	5662680	69.4%
24	21,30,34,41,44,49,53,60,71,78,79,84,89,98,103,107,109,119,123,130,134,138,157,167.	7830534	95.95%
36	2,4,9,14,17,22,31,36,39,40,42,47,59,65,67,70,77,85,90,95,97,99,104,106,109,120,130,133,135,140,142,145,153,154,167,168	8158599	99.97%
48	1,4,8,16,21,22,23,25,29,30,39,42,44,48,50,54,60,61,63,67,70,74,80,83,86,90,92,97,101,104,110,112,117,121,125,130,134,135,137,140,144,148,153,157,162,166,168,172.	8160634	100%
60	1,4,8,16,21,22,25,29,30,36,39,42,43,44,48,49,50,53,60,61,64,67,70,72,74,78,80,83,85,86,90,97,104,106,108,109,110,112,117,118,121,125,129,131,133,137,140,143,148,151,153,156,157,161,163,165,166,168,172	8160634	100%

Table 5.2 shows that with an increase the p value that represnt the number of the BSCs in 12, 24 and 36, the demand coverage increases in each scenario as well. However, when the model has been tested with $p = 48$, $p = 60$ and $p = 72$ we get exactly the same result as $p = 48$. Which means for the coverage distance, we do not need many facilities and the number of the BSCs that required to cover all demands can vary between 24 and 48. However, to further investigate the locations that provide high accessibility in a way that the average travel distance from the passenger demand to the BSC is minimized *P*-median location problem has been used and is explained in the next section.

5.14.2 BRIEF REVIEW OF THE *P*-MEDIAN LOCATION PROBLEM

Assume there is a set of n elements that represented by $i=\{1,2,3,4\ldots n\}$, and a set of j subsets of i that represented by $j=\{s_1,s_2,s_3\ldots s_m\}$. The mathematical model of *p*-median problem location problem has been formulated between (5.1) and (5.7). And the objective of using this mathematical model is to minimize the demand weighted total distance to improve the BSC accessibility.

5.14.3 THE MATHEMATICAL MODEL EXPERIMENTATION ON SPREADSHEET

According to the model description the experimentation on the spreadsheet is performed basing on the mathematical model of p-median which has been explained in section 5.9.1.Matrixes have been calculated corresponding to the objective function of the *p*-median model in equation (5.1). Note that SUMPRODUCT function deal only with arrays that have the same size, the demand $W_i[nx1]$ has been expended to matrix $W_i[nxn]$. Constrains setting in solver function is shown in Figure 5.8 and the number of BSCs can be set by changing MQ185 in solver parameters setting.

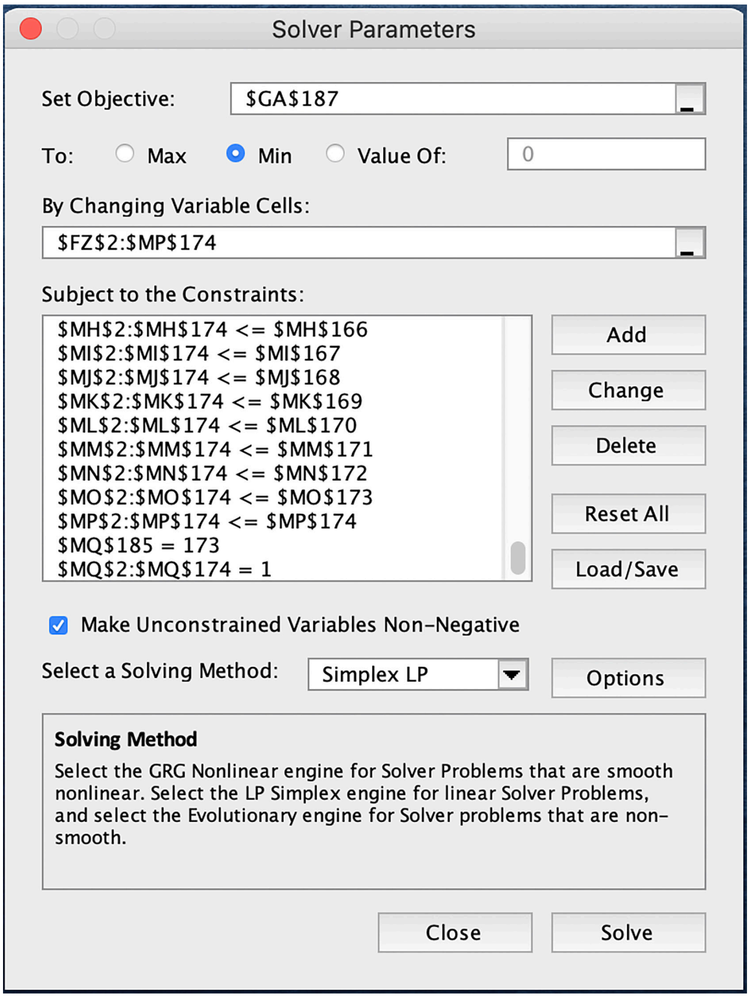

Figure 5.8 Solver setting of p-median problem

5.15 RESULTS ANALYSIS

The objective is to minimize the overall weighted passenger distance within a given number of BSCs. By using p-median, different outcomes have been calculated as shown in Table 5.3 . The relationship between BSC numbers and the demand-weighted average distance shows that the more BSCs open, the more accessible to the service network of BSCs, as illustrated in table 5.3.

Table 5.3 Demand - Weighted Average Distance Vs. The Number Of The BSCs Results Analysis

Number of given BSC	Location	Demand -Weight Total Distance	Demand-Weight Average Distance (Demand - Weight Total Distance / Total Demand
12	33,41,44,63,75,83,102,105,108,128,136,156	7472361	0.927
24	20,29,33,36,44,55,61,68,74,78,85,87,90,98,103,108,109,118,123,129,137,142,155,168	4795447	0.587
36	21,30,32,36,41,44,47,53,57,58,63,73,74,75,78,82,84,85,86,87,90,102,103,104,105,106,108,109,117,123,129,136,140,142,154,168	3534872	0.433
48	11,19,23,28,32,36,43,44,45,47,53,54,57,58,59,61,73,74,75,78,79,82,84,85,8687,88,89,90,91,102,103,104,105,106,107,108,109,117,123,125,127,129,136,140,142,154,168	2731524	0.334
173	1-174	0	0

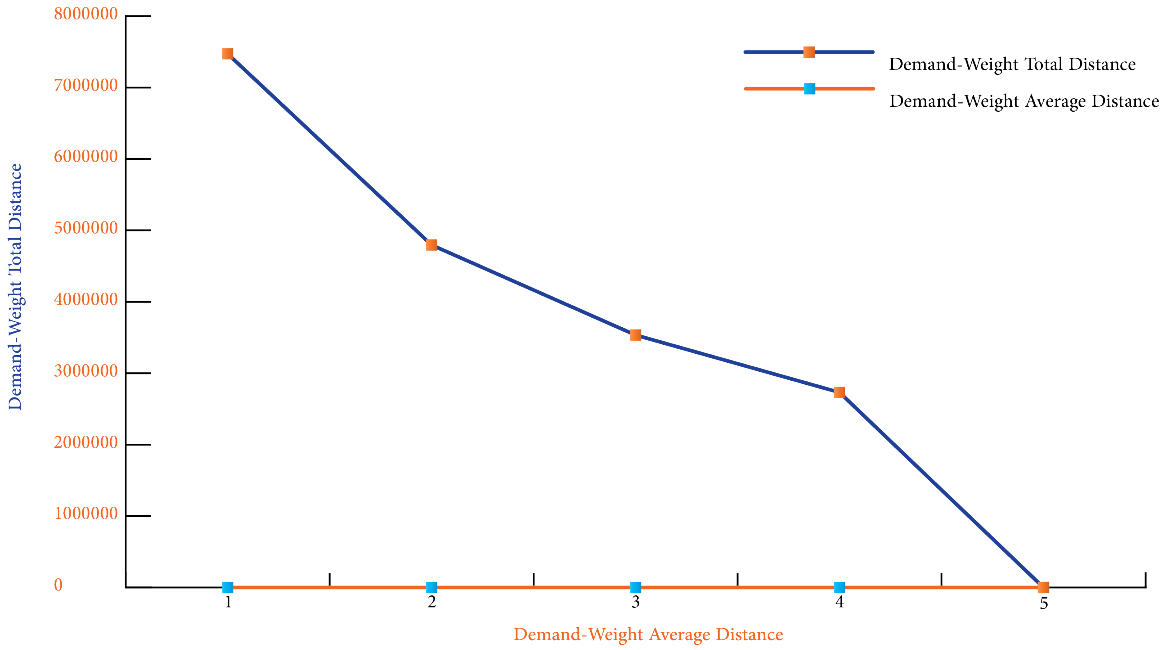

Figure 5.9 Demand- Weighted Average Distance Vs. The number of the BSCs Results Analysis

As mentioned earlier, the purpose of the optimization model that has been deployed here is to determine the optimal numbers of the baggage sorting centers (BSCs) and the best locations for them as well.

The results from both models MCLP and p-median location problem showed a mutual solution that can provide both high coverage rate for the service facility (BSCs) and at the same time high accessibility for passengers. There are 11 common locations for both assumptions (p=36,p=48) for both models as shown in Table 5.4.

Table 5.4 Shows There Are 11 Common Locations Between MCLP And P -Median For Both P = 36, P = 48 BCSs.

No. of BSCs	Locations According To MCLP	Locations According To *P*-Median	High Coverage%	High Accessibility
36	2,4,9,14,17,22,31,36,39,40,42,47,59,65,67,70,77,85,90,95,97 99,104,106,109,120,130,133,135,140,142,145,153,154,167,168	21,30,32,36,41,44,47,53,57,58,63,73,74,75,78,82,84,85,86,87,90,102,103,104,105,106,108,109,117,123,129,136,140,142,154,168	99.97	0.433
48	1,4,8,16,21,22,23,25,29,30,39,42,44,48,50,54,60,61,63,67,70,74,80,83,86,90,92,97,101,104,110,112,117,121,125,130,134,135,137,140,144,148,153,157,162,166,168,172.	11,19,23,28,32,36,43,44,45,47,53,54,57,58,59,61,73,74,75,78,79,82,84,85,86 87,88,89,90,91,102,103,104,105,106,107,108,109,117,123,125,127,129,136,140,142,154,168.	100	0.334

Moreover, between these mutual 11 locations for both models there are four locations that appeared in each solution set which are 90,104,140,168. In this case it can be said that four BSCs located in cells 90, 104,140 and 168 are enough to provide wide coverage with the minimum weighted distance.

5.16 SUMMARY

The complete dissociation would occur both within the ground and air segments of the passenger journey. It can be noticed that the dissociation in the ground segment is offered as an extra service in some large airports; however, until now there is no physical infrastructure that has been implemented on a large scale to make the dissociation concept be the norm rather than an extra service. As a conclusion, the dissociation within the air segment requires first dissociation in the ground segments, even though this condition is not sufficient for the complete end-to-end dissociation, but it is the first step that pave the way for the complete dissociation. Therefore, inspired by the existing parcel delivery networks, a New model of Baggage Ground Distribution Networks (BGDN) are of interest to be investigated as the preliminary step to implement the free baggage travel concept. Therefore, we can develop a two-stage optimization model for the design of the BGDN in Greater London. In the first stage, a maximal covering location problem is employed to determine the locations of baggage sorting centers (BSC). After which, a single source allocation problem is formulated in the second stage in order to assign the customers to different BSCs. The result has provided the optimal location plans for the BSCs in Greater London with respect to different scenarios.

CHAPTER 6

SATELLITE PASSENGER TERMINALS

6.1 INTRODUCTION

Chapter 6 provides a brief overview of the airport terminal design process and survey terminal functions and operations involving passengers and terminals. The main focus is off-loading passenger and baggage processing outside the main airports. The concept of satellite terminals (Off-Airport Terminals) appears to be new and has not been considered in literature before. The benefits of satellite terminals (OAT) are linked to solving the congestion problem at airports and to the current methods of airport terminal configurations.

6.2 AIRPORT TERMINAL AND TERMINAL OPERATIONS

The airport terminal is the main interface between the airfield side and the rest of the airport, it represents the link that connects the land-side operations to the air-side operations. Therefore, terminals are the main airport building for passengers, which starts from the terminal curb side and extends to the screening checkpoint, including the concourse beyond this point. These buildings offer many services for the airlines and for their passengers. Such services include, check -in, security, customs and immigration. They may also provide commercial or non-aviation facilities such as food and beverage areas, retail stores, entertainment places, and Internet facilities. Generally, demands for the airport facilities are dictated by the type of the airlines that operate at these airports. For example, the regional airport with point-to-point flights will mainly generate demand for the standard services such as ticketing, check-in, baggage drop-off and screening. Also, they include other services, like baggage reclaim, gate management, security, and ground transportation services to/from the airport. While international airports with hub-and-spoke airlines require extra services such as transport between terminals, baggage transfer, retail and food facilities. However, the demand for basic services, is proportionally reduced. The level of services that are offered at the terminal is subject to competition among the airports. For instance, the volume of international transiting passengers at large airport hubs have a direct impact on their revenue. Furthermore, airport terminals that process international passengers are required to comply with the immigration and customs regulations of the country.

The time spent by passengers at the terminal facilities can vary significantly. For example, passengers spend more time for shopping or at food courts than queuing at service points or commuting between terminals. A summary of the airport services related to passenger and baggage processing are provided in Figure 6.5. Note that, not all passengers are equal, so their needs, expectations and levels of tolerance can be very different. The basic passenger characteristics are: business vs. leisure, departing vs. arriving, domestic vs. international, transiting vs. terminating, and those on scheduled vs. chartered flights. Therefore, maintaining the passenger experience with all this variety and with the current continues growing, is one of the key development indicators for the airports.

6.3 AIRPORT TERMINAL MODELS

Airports can be categorized into two different models: centralized and decentralized. For a single airport terminal, the centralized processing of passengers and baggage has a number of advantages. These include better utilization of the available infrastructure, minimum staffing requirements, easier handling of the connecting passengers, same availability of services to all passengers, and simpler surface travel to the airport. On the other hand, the decentralized airport with multiple terminals benefits from increased processing capacity for both passengers and luggage. Furthermore, it enjoys duplication of the facilities, higher staffing and equipment requirements, and more complex management of airport operations. The types of passengers and their needs affect the airport design process, where the main objectives for an efficient design are sharing of facilities, operations management and performance objectives [75]. However, the airport design perspective varies substantially among different airports, thus there is no single set of design standards which is valid for all airport types. For example, the domestic terminals or terminals serving low-cost carriers have different requirements than those serving national carriers and international passengers. Apart from building new terminals, the airport capacity can be increased by expanding and redesigning the existing terminals. When the terminal grows, at some point, it may start resembling a decentralized facility. In large terminals, for example, the walking distances may be too long to have only one check-in area and one security checkpoint. In such cases, some facilities would be duplicated to provide multiple paths for different groups of passengers while other facilities can remain centralized. In addition, the terminal facilities may not be utilized uniformly throughout the day. The peak hours demand the terminal capacity to experience much larger volumes of passengers than in other non-peak hours. If the difference between the peak-hour and the average demand, is large, efficient and economical utilization of the airport terminal is problematic.

6.4 AIRPORT TERMINAL DESIGN

Any airport consists of a number of stakeholders and strongly interacting services, in which the terminal building is the main interface between the airfield and the other areas of the airport. As the main function of the airport terminal, is the provision of convenient transfer facility from the land-side to the air-side and vice-versa. These buildings should have a suitable layout to enable a convenient passenger experience during the whole journey. Airport terminals usually serve various needs for different passenger types: arriving, departing and transferring.

There are four standard terminal design layouts to specially distribute basic service and process areas from the curb to the boarding gates at the airport, which are summarized as follow:

- LINEAR CONCEPT

Is the most straightforward design with adjacent single passenger processing area. This is separated from a single hold room area by a security checkpoint, followed by an aircraft-parking apron with gates. Although variations of this design are widely used in many airports, it is more appropriate for low activity regional airports without international connecting passengers. The main advantage of this design is simple and relatively short walking distances. The main disadvantages rendering this design obsolete are the limited capacity by a single security screening checkpoint, limited concession revenues, and limited opportunities for expansion.

- PIER CONCEPT

Extends the linear concept with a long hold room concourse, with gates on both sides to increase the capacity and the walking distances. A network of piers with multiple passenger processing feeds may be sufficient for some busy hub airports.

- SATELLITE CONCEPT

Creates an air-side concourse with hold rooms, concessions and other passenger amenities, which are completely surrounded by apron gates. Therefore, overhead or underground connectors from the land-side area are required. The walking distances to the concourse are too long, hence, some people-moving systems should be used. The main feature of this design is that passenger and baggage processing and air-side operations are completely separated and can be developed independently. The disadvantage is longer taxiing distances for the aircraft than in the other two designs. Moreover, there is a substantial additional cost for interconnecting the input passenger facility with the satellite concourse. However, this concept can provide sufficient capacity to support very busy airports with a mixture of terminating and connecting passengers. Since the concourse is often designed with a pier layout, the capacity expansion can be achieved by enlarging the piers, or by building additional satellite concourses.

- TRANSPORTER CONCEPT

Further developments to the satellite terminal design to provide complete separation of passenger facilities from those which are required for the aircraft side services. The original design assumed mobile lounges serving as hold rooms, which transfer passengers from the central terminal building directly to the aircraft on the apron. The design later evolved into a more simple solution with buses that drop off passengers to the aircraft. In this design, the aircraft parking stands on the apron are more flexible, and the airport has more flight handling capacity. However, the main disadvantage is that servicing the aircraft is much more demanding and the cost of operating the bus service can be large. The journey of passengers from the hold room to boarding the aircraft is much slower, and the passenger are exposed to weather conditions. This can be a problem for both airlines that require fast aircraft turnaround and for the business passengers since they may have to accept longer dwelling time at the airport. However, the airports may easily resort to the apron aircraft operations to handle the peak hours without requiring much larger investments for redesigning the terminal and increasing its capacity. In practice, airport terminals are often constructed to combine all these four basic designs to pragmatically manage the passenger volumes and flows as required. Examples of the terminal designs with distributed layouts are given in Figures 6.1, 6.2 and 6.3 [76].

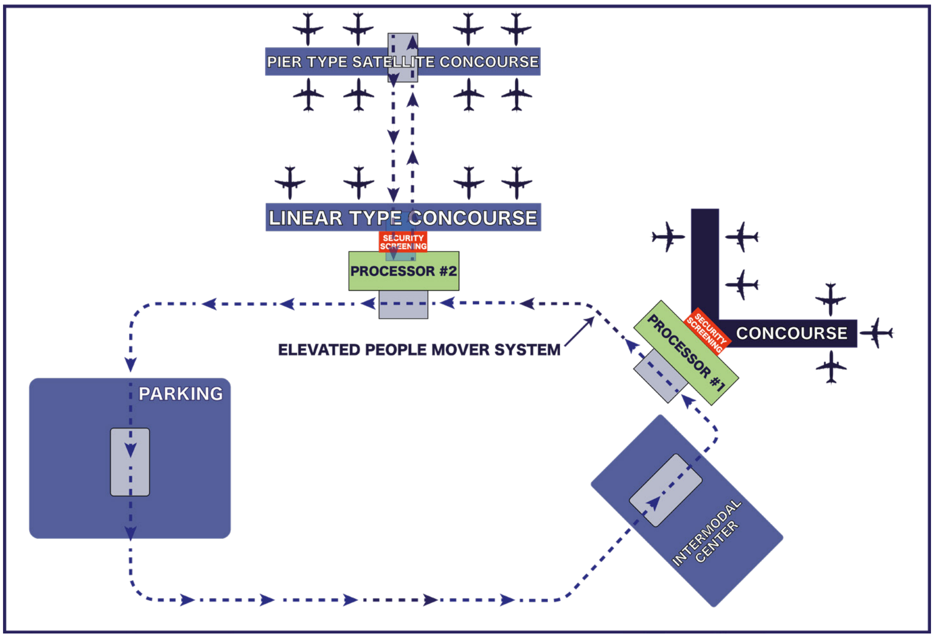

Figure 6.1 Terminal Design With Concourse Building Detached As A Single Spine Mover

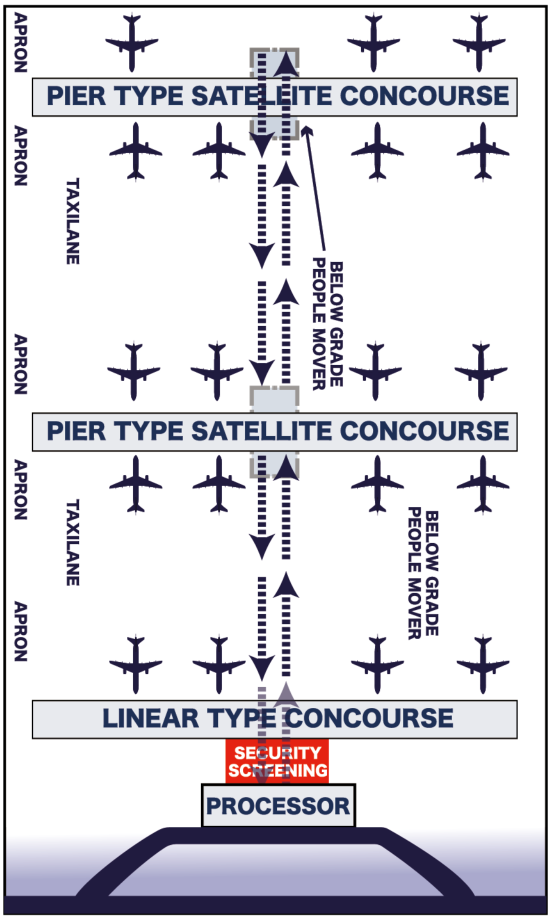

Figure 6.2 Terminal Design Withcconcourse Building Detached As Multiple Spine Mover.

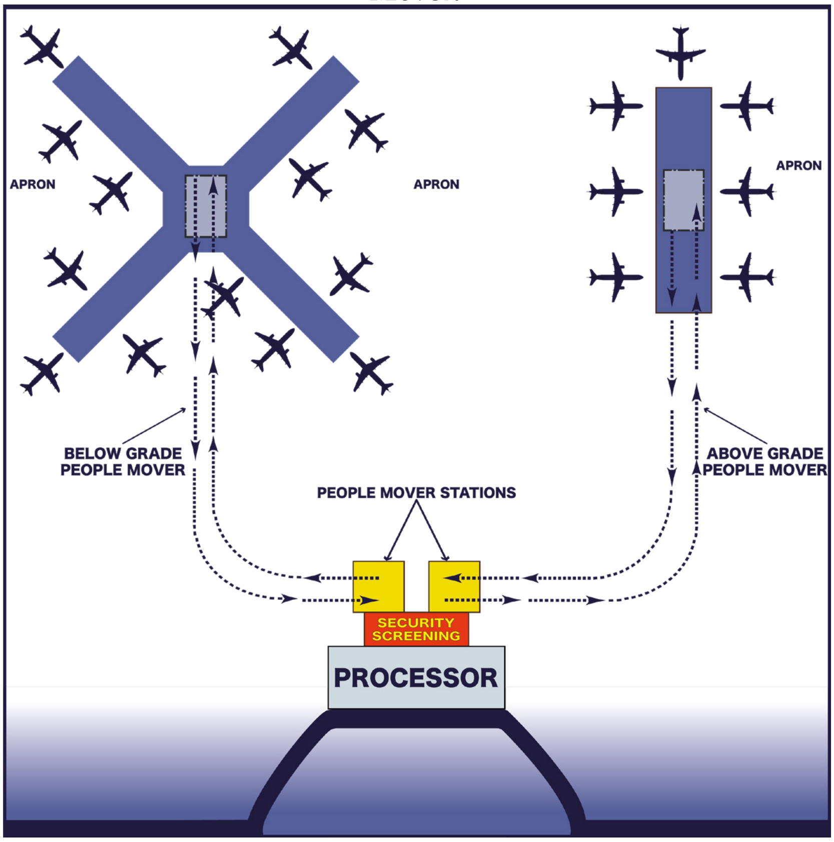

Figure 6.3 Terminal Design With Cconcourse Building Detached As Loop Mover.

6.5 AIRPORT TERMINAL MANAGEMENT

Managing the passenger flow requires knowledge of the passenger distribution and predicting the on-time flight performance. Efficient terminal designs allow mixing of different passenger flows for the maximum utilization of the available spaces at the airport. The staffing levels should be dynamically optimized to provide services only when there is demand, and to minimize the service queuing. Since passenger processing is organized in flows, the service disruption at one point will affect all other service points. The services prior to the disruption may have to slow down the passenger processing whereas the services located after the disruption will be starved. Hence, accurately forecasting the service demand is vital for the smooth terminal operations. The planners and managers increasingly rely on mathematical models, historical data, activity patterns and real-time information. Collaborative decision making (CDM) systems have grown in popularity in the recent years to avoid the network effect of cascading disruptions. For instance, a few minutes waiting time can be easily amplified by the services network into a much larger delay. The CDM systems exploit data sharing by multiple parties at the airport. This matter has a positive impact on stabilizing the airport processes, better utilization of resources, and making the processes more predictable.

6.6 AIRPORT TERMINAL SERVICES:

Figure 6.4 illustrates the typical airport services for both arriving and departing passengers and Figure 6.5 provides a summary of the airport terminal services that are related to passengers and baggage processing. This service chain connects the main functional areas at the airport, as experienced by any typical passenger, when the airport is used as inbound for an arriving passenger or as outbound for a departing passenger.

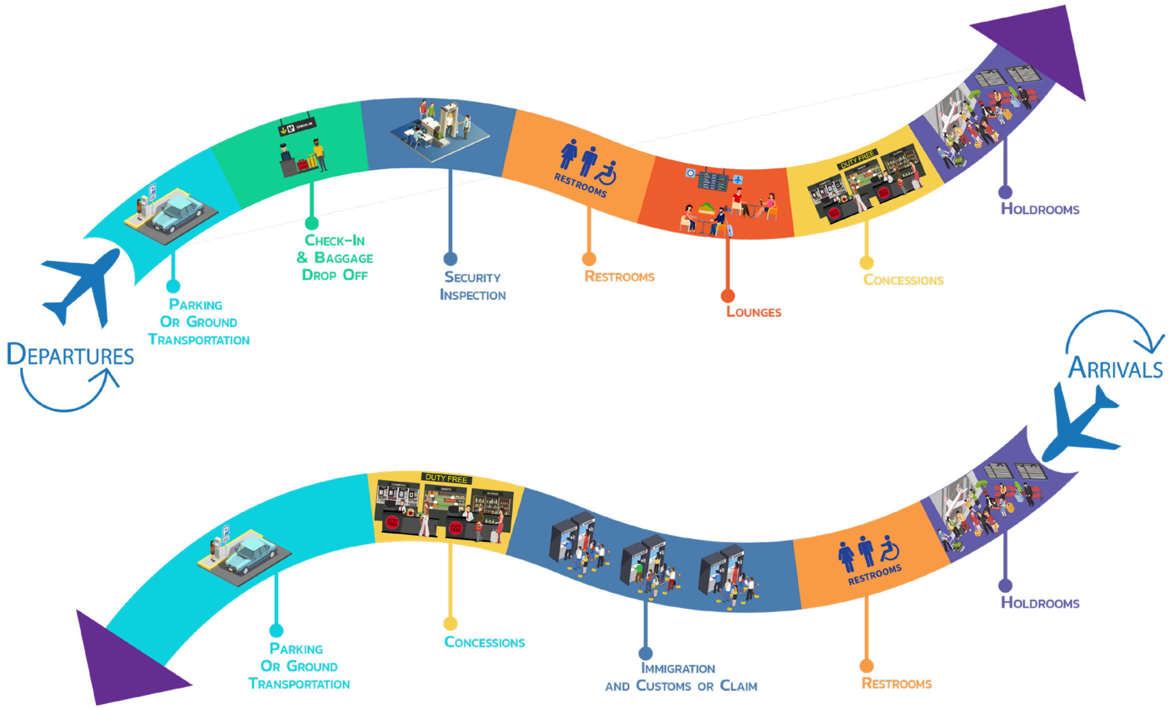

Figure 6.4 Airport Services Chain

Passengers and Baggage Processes at the Airport Terminal

Baggage Services

- Staffed Counters
- Self Drop-off
- Self Tagging Stations
- Online & electronic self-tagging
- Reclaim on Arrival
- Transfer Bags
- Lost Bags Reconciliation
- Trolleys / Carts

Check-in Services

- Staffed Counters
- Self-Service Kiosk
- Self Tagging Stations
- Online and Mobile Check-in

Terminal Services

- Flight Information Display and Announcements
- Concessions & Shops
- Lounges
- Food Courts
- Money Exchange
- Internet Access
- Waiting Areas & Airport Hotel
- Trolleys / Carts

Terminal Amenities

- Security Screening
- Boarding Management
- Boarder Control & Immigration
- Customs
- Information Desks
- Customer Service Counters
- Ticketing &Transfer Counters
- Services for Disabled Passengers

Figure 6.5 Outline Of Services For Passenger And Baggage Processing At Terminals.

6.7 PASSENGER PROCESSING AT THE AIRPORT TERMINAL:

The main objective of the airport terminal design, is providing efficient and smooth passengers movements. Passenger processing at the terminals can be characterized under three fundamental components [77]:

7. Access interface: which enables passengers, baggage and visitors to enter and exit the airport terminal. This includes parking, circulation, curbside loading and unloading.

8. Processing system: refers to the different activities of processing passengers and luggage during the arrival and departure at the airport such as ticketing, check-in, customs, security, immigration etc.

9. Flight interface: includes departure lounge, security facilities used for passenger inspection purposes, airline operation spaces used by airline personnel, and equipment related to arrival and departure of the aircraft.

Different domain passengers must pass through, to board the aircraft at the departure or to get off the aircraft at the arrival as presented in Figure 6.6. Between these processing domains, passengers can undertake different discretionary activities such as using washroom facilities, shopping or going to the cafés, etc...

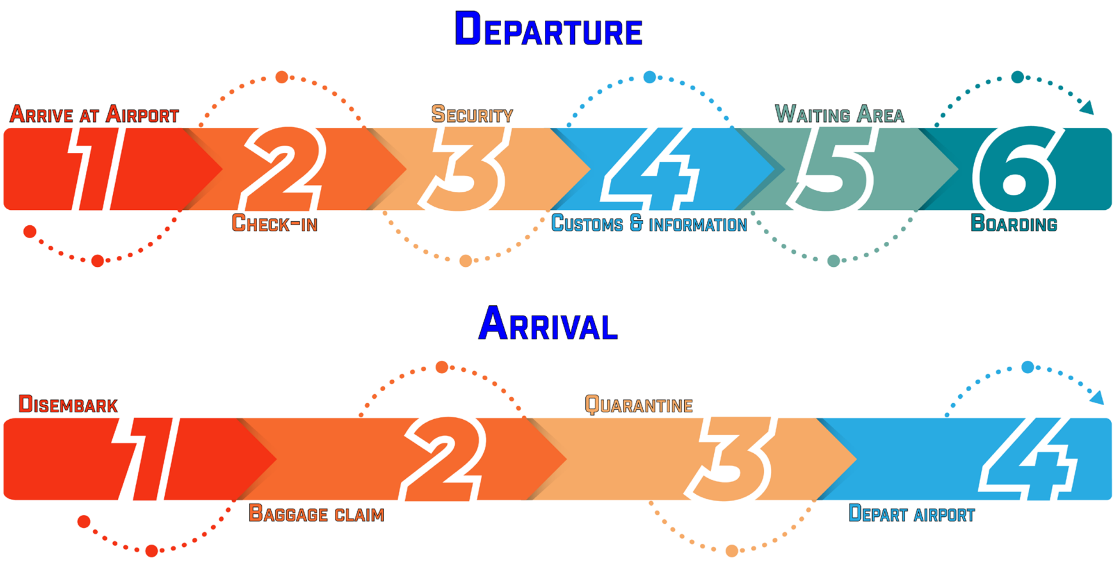

Figure 6.6 The Different Domains Of Both Landside And Airside At The Airport Terminal

6.7.1 CHECK-IN

A check-in domain contains counters, queuing area and service facilities such as flight information counters, telephones, toilets, greeters waiting area and café [1]. An efficient and fast check-in process is essential in processing passengers, since poor layout of passengers queuing could result in airport congestion. Nowadays, design of the check-in facilities have experienced rapid changes due to security reasons, rapid development of electronics, and innovative changes in the ticketing system. Such changes cover the use of electronic ticketing and online check-in. In fact, using these facilities will reduce the passenger processing time at the airport. They may, even, convert the notion of a traditional check-in and make the check-in halls obsolete in the near future.

6.7.2 OFF-AIRPORT PASSENGER CHECK-IN

According to SITA (2017), 80% of passengers book flights using the web. 7% use the mobile application, and only 13% use a face-to-face meeting with a travel agent. 46% of passengers visit the check-in counter at the airport, 33% use the web or mobile application check-in, 15% use the self-service kiosk at the airport, and 6% utilize automated check-in. As most passengers prefer flexibility and self-reliance, face-to-face check-in at the counter is likely to diminish further. In addition, airline service kiosks can be put into the hotels and railway stations, even though, this does not seem to be a widespread practice. Service kiosks at airports can be used to confirm or change reservations, obtain boarding passes, enter advanced passenger information, and choose seating [78].

One challenge with Online check-in, is to submit accurate advanced passenger information. This information needs to be verified at the airport, for example, by scanning the travel document. The Online check-in usually enables only within a certain time window, prior to the flight departure. The main advantage of Online check-in for airlines is that it frees resources at the airport, and the passengers can avoid queuing at check-in counters.

In addition, airlines are liable for international passengers to satisfy the entry requirements of the destination country. The valid travel visa and passenger identity are still checked manually at airports. However, there are already face recognition and other biometric-based trials to automate these processes.

6.7.3 OFF-AIRPORT BAGGAGE DROP-OFF

Unlike Online check in, the remote baggage drop-off is much more challenging. It is a complex concept that has many critical issues such as security issues, passenger concern and financial issues regarding investment. The main stakeholders in the off-airport baggage drop-off process are airports, airlines, and passengers. For the airports, it is essential that this service operates according to the airport specifications, and without hindering the other operations. While for the airlines, this service should be considered as an actual service for passengers. Since, both security and liability issues are covered. While for the passengers, this service should be transparent, not expensive and reduce the hassles of traveling. The actual implementation of the off-airport baggage drop-off systems should be considered on a case-by-case basis. Many off-airport baggage drop-off solutions have been implemented at different airports. However, not every solution is suitable for all situations at other airports [21]. A survey of the existing off-airport baggage check-in, and drop-off solutions has been presented as follows: Self-service check in and manned baggage drop-off points operated by Continental Airlines are provided next to the parking lot outside the Houston airport. In some cities such as Frankfurt, Madrid, Los Angeles, Vancouver, and Sydney, the railways connecting the airports offer remote check-in and baggage drop-off at the stations. Similar services have been offered by a growing number of airlines, including Japan Airlines, KLM, British Airways, Lufthansa, Air France, Continental Airlines, and Qantas Airways. In large cities, the 3rd party private courier companies offer baggage collection and drop-off services. These are carried out, usually, within defined regions and subject to an agreement with a specific airline. On several occasions, the off-airport baggage drop-off was offered, but eventually the service was terminated due to unsustainable investment, operational costs, and relatively low adoption rates.

6.7.4 SECURITY

Airport security interface is arguably the most serious aspect of the airport operations, and should be balanced with an efficient management of the passenger flow. Since the earliest days of civil aviation, security was the vital aspect of the airport design and planning processes. However, complexity of the security sector has increased recently, since this domain witnessed dramatic changes, especially after the terrorism attacks of 11 September 2001 in New York [79]. Screening processes can vary among the airports, but usually include walk-through detection devices, X-ray machines for handbags, and space manual search and X-ray items recovery.

6.7.5 CUSTOMS AND IMMIGRATION

At international airports, passengers should present their passports, boarding and departure cards to the customs officer. Their details will be checked and their right to fly will be confirmed. Customs and security are strongly bound since passengers have to proceed directly from one domain to the next, while distinct stakeholders control each of them customs are controlled by a Government Agency; and security controlled by a specialist private company [1].

6.7.6 BOARDING

The Boarding process is an airline's responsibility and it can only start when the aircraft is ready for departure. The main procedure at this domain is checking the Boarding cards and passports at the gate by the airline staff, then boarding the aircraft by passengers. Usually, the layout of this domain varies from one airport to another. For example, some airports have a specified waiting area for each flight passengers to wait in this enclosed area. While, other airports use a common open space and the passengers are free to leave the area. Note that each boarding area has a seating space for passengers to allow them to arrive early and await boarding [80].

6.7.7 DISCRETIONARY PERIODS

Passengers spend most of their discretionary time when they are at the airport under the airport control itself. Around two thirds of the passengers' total time at the airport, is experienced in these areas. For a departure, there are three periods, where the passenger has discretionary time: pre-check-in land-side; post check-in land-side; and air-side. At these periods, passengers are provided with the opportunity to shop, eat, and rest.

6.8 CONCEPT OF SATELLITE TERMINALS(OATS)

According to the statistics that were presented in chapter 2, many large airports face congestion problems in their terminals. Different studies in the literature have identified the check-in process as one of the bottleneck processes that causes the congestion problems. A significant number of the proposed solutions are focused on changing inside the airport terminal to solve this problem. However, redevelopment of the current terminals is a solution with restricted long-term possibilities. Since this can increase capacities to a certain level and with the continuing traffic growth, many facilities will definitely face problems with their activities in the future. The idea of building Satellite terminals to solve congestion in delivery networks was proposed almost two decades ago [81]. These terminals were shown to expand the capacity of the cargo transport hubs that are often constrained by the available land and environmental conditions. Here, this idea is evaluated for passenger traffic to supplement the capacity of the existing airport terminals. This is achieved by transferring some of the passenger and baggage processing functions to the new sites, relatively far from the airport. Note that, the proposed Satellite terminals (OAT) should not be smaller versions than the major airport terminals. Rather they will perform only specific airport processes, which can be hived off the airport building without any serious disruption to the current airport operations. Since off-loading the check-in is more straightforward, the main concern is about off-loading the baggage drop-off from the airport terminals. Note that about 60% of the respondents of the SITA Passenger Self-Service Survey, showed that passengers would use the off-airport baggage drop-off systems, if available. Moreover, around 42 % would be happy to pay for such services [82].

6.9 THE SATELLITE PASSENGER TERMINAL(OAT) SERVICES

Here, the concept of OAT is considered as a new attempt to introduce sustainable and profitable off-airport passenger and baggage processing service. The OAT is a facility built in a suitable geographical location, and offer the following services to the airline passengers:

- Passenger check-in, pre-departure ID and visa checks
- Baggage drop-off, screening, and collection on arrival with optional delivery.
- Concessions, money exchange, food courts, lounges.
- Travel agents, information desks, car rentals.
- Flights information, Internet access, entertainment.
- Hotel accommodation and long-term parking.
- Direct shuttle or other public transport to and from the nearby airports.

The viability of the satellite terminal or the OAT is critically dependent on selecting a suitable location. The location can be far away from the expensive areas, which are often found near large cities or busy railway stations. The location should have easy surface access from other cities in the region, and there should be plenty of room for a low-cost long-term parking. Moreover, the location should be chosen to serve more than one airport to increase its utilization, and to improve the economic viability. In order to avoid substantial costs for new shuttle services to the airports from the OAT, the location should exploit the existing railway and bus links to run these new shuttles. The OAT would then be used as the endpoints of the passenger journey, and offer many services that are currently provided at the departure and arrival airports. As a case study specifying the best locations for these terminals have be implemented for the United Kingdom as explained in section 6.14.

6.10 THE ANTICIPATED BENEFITS OF THE SATELLITE PASSENGER TERMINALS(OATS)

The possibility of developing the OATs have been proposed as an option for solving the congestion problems and permit airports to manage the continuous traffic growth.

The anticipated benefits of implementing this concept can be summarized as:

- Freeing a substantial processing capacity of the existing airports to extend their life without the need for their expansion.
- Encourage passengers to use shuttles and other public transport to the airports for relieving the curbside congestion.
- Provide an overall better experience for passengers, even though their journey to the departing airport now has two segments. These cover a relatively short travel from home to the satellite passenger terminal, and a convenient travel on public transport from the satellite terminal to the airport.
- Create opportunities for new business models to finance the development and services at the satellite terminals by the government, the airports and the airlines.
- Overlay the cargo delivery to a network of satellite terminals.
- Stimulate the local economy adjacent to the satellite terminal by creating jobs and business opportunities.

Figure 6.7 depicts the surface network involving th OAT. Although some (e.g. business) passengers may still prefer direct travel, other passengers should be rewarded with an incentive to utilize the new facility.

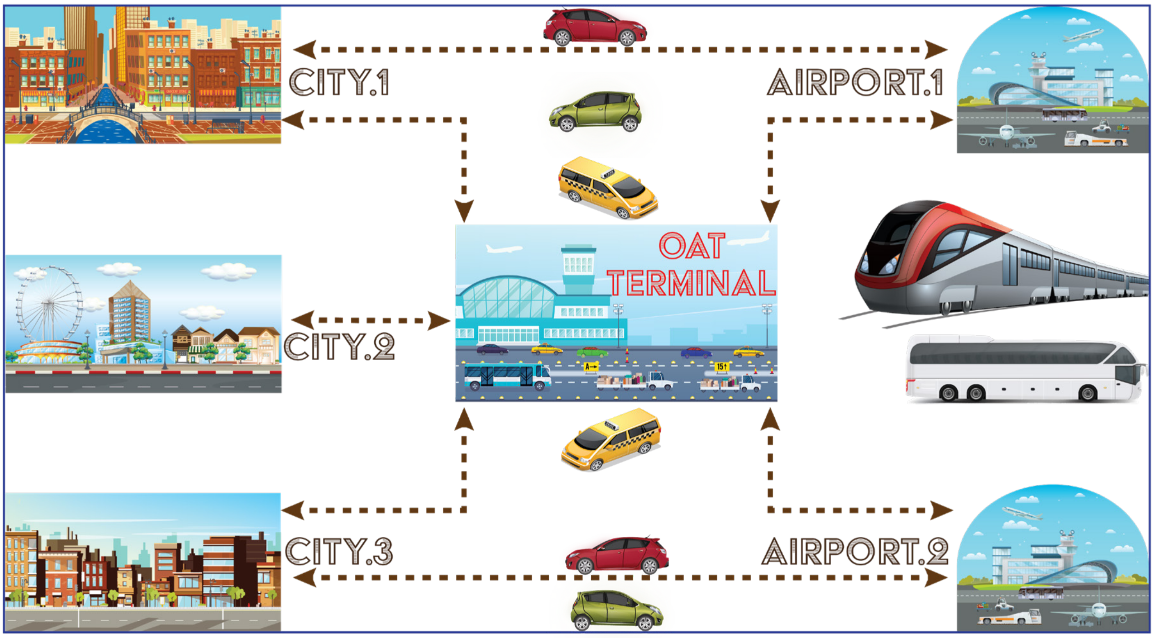

Figure 6.7 The Surface Network Of passenger Travel To The Airports Created By The Proposed Concept Of Satellite Passenger Terminals.

6.11 RISKS OF SATELLITE TERMINALS (OFF-AIRPORT TERMINALS):

The risks that may combine adapting this kind of terminal can be summarized as :

- Possibly large investment (acquiring land, construction of the terminal) i.e. capital expenditures.
- Guaranteed travel times between the terminal and the airport.
- Having enough capacity for commuting passengers and luggage to/from the airport, but not too much capacity to minimize operational costs.
- Sustainability of operation, especially economic model (operational costs).
- Business models: who pays for building the terminal and its operation; there needs to be policies to enforce or just encourage the use of terminal, probably incentives will be needed
- Environmental footprint: just expanding Heathrow with another runway created a lot of concerns about ecology and environmental impact.

- The system gets more complex, so there are more chances something goes wrong. For example, the train connection between the terminal and airport cannot be used due to an accident.

6.12 THE UNITED KINGDOM AVIATION CONTEXT

The UK is considered as one of the best-connected countries in the whole world, it has a diverse and competitive airport system that offers many destinations and a greater number of seats than any other country in Europe. However, the UK aviation system ability that is required to respond to the global aviation trends and to meet the country connectivity needs, is more limited by the current capacity constraints. The capacity constraints have a significant impact on the UK's connectivity system. In fact, with no space for additional flights at Heathrow airport and less available capacity at Gatwick airport, it is affecting the long-haul connections that focus on the most profitable routes. This matter will prevent the development of new links that emerging markets and as a result, it will affect the UK business growth and productivity in the area.

As an example, Heathrow airport's status as the international hub for aviation is being eroded. The airport route networks to be able to grow it needs to attract considerable levels of the international transfer traffic that supplement the local demand. There are many obstacles that cause difficulties for Heathrow airport to attract these transfer passengers such as decline the domestic connectivity, limited resilience and pressures on fares.

It is obvious that capacity constraints increasingly affect the ability to travel conveniently, cheaply and to a wide range of destinations, the matter definitely impacts the UK's hub status and the whole economy as well. According to the Airports Commission Final Report in 2015, the cost analysis suggested that failing to address the existing capacity constraints could amount over the next 60 years to £21-23 billion to the users and providers of the airport infrastructure and £30-45 billion of cost to the whole economy [83].

In fact, in a competitive and complex global environment, it would be perilous and short-sighted to place the UK's world-leading connectivity at risk by failing in addressing these constraints. Therefore, in the next section the UK has been chosen to investigate the location problem for proposed satellite terminals.

6.13 THE UK MAP ANALYSIS

To investigate the location problem the UK, a map of 311 cells with cell size [LxH] = [36 kmx36 km] has been used as shown in Figure 6.8 . Note that, this division has been created using the ArcGIS software following the same steps that were explained before in Chapter Five to produce a London map , for more details of the tools that have been used in the software, see reference [84].

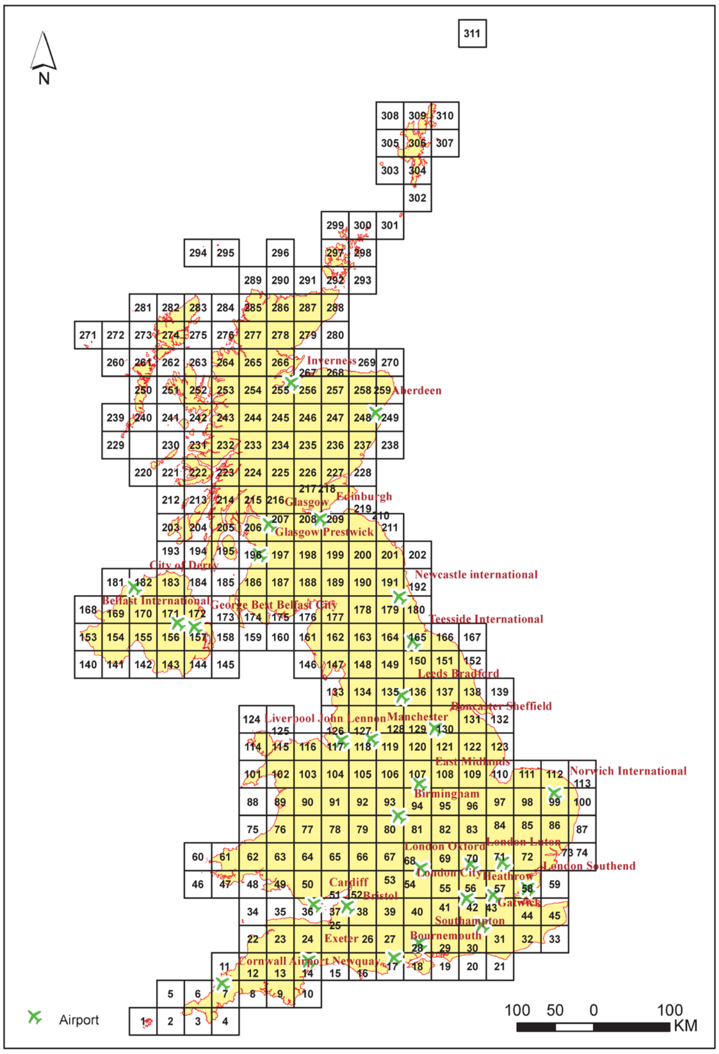

Figure 6.8 Map of The UK Contains 311 Cells

Also, following the same procedure that has been used to allocate the BSCs in Greater London, the locations for the satellite terminals that provide the best coverage has been concluded in this chapter. However, due to the complexity of the modelling system, only the MCLP model has been used.

6.14 ASSUMPTIONS AND PARAMETERS

The model has been formulated as follows:

1. The customer demand is proportional to the population, the demand matrix presented in Appendix G. The required data has been collected from UK Data Service [85].

2. Set of candidate locations ,the candidate locations are aggregated and represented by the grids, which mean we have 311 candidate locations for the Satellite Terminals (OATs).

3. Set of locations where the demand from customer *i* can be covered

To generate the coverage matrix, we assume that coverage of the satellite terminal is preferable within a unit distance (length/width of each grid). If the distance between the terminal and the customer zone is less than or equal to one unit distance, the demand of the customer zone can be covered by that satellite terminal. As mentioned earlier, the locations of these terminals should be chosen to serve more than one airport to increase its utilization. As shown in Figure 6.8, the UK airports are quite close to each other so the proposed locations should serve more than one airport at a time.

After the parameters have been set, the MCLP is coded and solved using openSolver and the objective was maximizing the coverage demands with a limited number of proposed satellite terminals to be opened. Different network configurations have been tested with 10, 15, 20, 25, 30, 35, 40, 45, 50, 55 and 60 satellite terminals.

6.15 RESULTS ANALYSIS

The objective is to choose the location for the satellite terminals that maximize demand coverage. This has been done based on a suggestion that the required number of the satellite terminals is 10 then this number is increased by five in each test. By keeping the maximal coverage equal to 1-unit distance, the outcomes with respect to different number of wanted terminals are presented as follows:

Table 6.1 Relationship between wanted satellite terminals numbers and the coverage under the condition that ds = 1 unit distance in MCLP model

Number of Terminals	Locations	Covering
10	29,44,52,81,106,117,129,134,208	41386908
15	18,30,39,44,51,55,71,80,95,105,120,126,135,180,208	4949784
20	13,17,18,30,37,44,50,55,71,80,86,95,105,120,126,131,135,156,180,208	54657351
25	10,13,16,17,18,124,30,39,44,50,55,66,71,81,87,96,106,117,129,134,138,156,180,207,218	5879633
30	8,10,13,14,16,17,18,19,24,31,38,44,50,55,67,71,82,86,92,97, 107,117,122,128,133,138,156,180,207,218	62232462
35	8,9,10,13,14,15,16,17,18,19,20,21,24,27,38,40,44,50,57,167, 72,82,92,97,99,107,117,122,128,133,137,156,180,207,218	65167837
40	7,8,9,10,13,14,15,16,17,18,19,20,21,24,27,29,39,44,51,56,63, 68,72,79,84,95,99,106,117,122,129,134,138,156,162,165,191 ,207,218,248	67214824
45	6,7,8,9,10,13,14,15,16,17,18,19,20,21,23,24,27,28,29,44,51,52,56,63,68,72,79,84,95,99,106,117,122,129,134,138,156,162, 165,171,191,198,206,218,248	68815407
50	4,6,7,8,9,10,11,12,13,14,15,16,17,18,19,20,21,21,22,23,24,27 ,28,29,31,36,45,52, 56, 63, 68, 72 ,78 ,83 ,93, 99, 108, 110, 117, 118, 129, 134, 156 ,162 ,165 ,171 ,191 ,198 ,206 ,218 ,248	70187381
55	4 ,6 ,7, 8 ,9 ,10 ,11, 12 ,13, 14, 15 ,16 ,17 ,18, 19 ,20, 21, 22 ,23 ,24 27, 28 ,29 ,31, 36 ,45 ,52 ,56, 63, 68 ,72 ,78 ,83 ,93 ,99, 102, 108, 110, 117, 118 ,129 ,131 ,134 ,151 ,156 ,162 ,165 ,169, 184, 191, 198 ,206 ,218 ,225 ,248	71224746
60	3, 4, 6, 7, 8, 9, 10,11, 12,17,14, 15,16,17,18,19,20,21,22,23,24,25,27,28,29,30,31,36,45,52,56,63,68,72,78,83,93,99,102,1088,110,117,118,129,131,134,151,156,162,165,169,184,191,196,198,210,216,227,248,256	71993661

Note that the covering value kept changing every time the test was stopped since there is no need to keep increasing the number of the terminals while the locations that are close to the current airports have been covered at p = 60. Depending on the current airport's location on the map we assumed that the coverage of the satellite terminal is preferable within a unit distance (length/width of each grid) that contains the main airport as depicted in Table 6.2.

Table 6.2 The Potential Locations for The Satellite Terminals

Airport	**Locations**				
Newquay Cornwall Airport	6	7	8	11	4
Exeter International Airport	13	14	15	10	24
Bournemouth Airport	16	17	18	27	
Southampton Airport	27	28	29	18	40
Gatwick Aiport	29	30	31	20	42
Cardiff Airport	35	36	37	50	24
Bristol Airport	36	37	38	25	51
Heathrow Airport	41	42	43	30	56
London City Airport	42	43	44	31	57
London Sothend Aiport	57	58	59	44	72
Luton Airport	69	70	71	56	70
Stansted Airport	70	71	72	57	84
Birmingham International Airport	93	94	95	81	107
East Midlands Aiport	116	117	118	104	126
Liverpool John Lennon Airport	117	118	119	127	105
Manchester Airport	121	120	122	130	108
Doncaster Sheffield Airport	134	135	136	128	149
Leeds Bradford International Airport	164	165	166	180	150
Durham Tees Valley Airport	178	179	180	164	191
Newcastle Airport	155	156	157	143	171
Belfast International Aiport	156	157	158	144	172
George Best Belfast City Airport	195	196	197	206	186
Glasgow Prestwick Airport	206	207	208	197	216
Glasgow International Airport	207	208	209	217	198
Aberdeen Airport	247	248	249	237	258
Inverness Airport	254	255	256	266	245

The results produced from the MCLP model showed the best locations for the proposed terminals are given in Table 6.3.

Table 6.3 Locations of Satellite Terminals According to MCLP

Airports	Locations				
Newquay Cornwall Airport	6	7	8	11	14
Exeter International Airport	13	14	15	10	24
Bournemouth Airport	16	17	18	27	
Southampton Airport	27	28	29	18	40
Gatwick Aiport	29	30	31	20	
Cardiff Airport	36	50	24		
Bristol Airport	36	38	51		
Heathrow Airport	30	56			
London City Airport	44	31	57		
London Sothend Aiport	57	44	72		
Luton Airport	71	56			
Stansted Airport	71	72	57	84	
Birmingham International Airport	93	95	81	107	
East Midlands Aiport	117	118	126		
Liverpool John Lennon Airport	117	118	105		
Manchester Airport	120	122	108		
Doncaster Sheffield Airport	134	135	128		
Leeds Bradford International Airport	165	180			
Durham Tees Valley Airport	180	191			
Newcastle Airport	156	171			
Belfast International Aiport	156				
George Best Belfast City Airport	196	206			
Glasgow Prestwick Airport	206	207	208		
Glasgow International Airport	207	208	198		
Aberdeen Airport	248				
Inverness Airport	256				

Note that the highlighted green locations are the mutual solutions that appeared more than once in each solution set as described in Table 6.1.

The results based on set maximal location model shows that each airport needs at least one OAT in order to cover all demands. The performance of the relocation decisions assumed that all the unit distances can be considered as the candidate locations for relocating the OAT. The objective of maximal covering location model seeks for maximize coverage with minimum number of service facilities. However, in this case may lead to high investment cost, low accessibility or responsiveness. Therefore, from the beginning it was suggested that the OAT should be shared between more than one airport.

As shown in Figure (6.8) there are many airports on the map that seem to be close to each other.

Under the condition of 60 facilities allowed, OAT can be located at cells (3, 4, 6, 7, 8, 9, 10,11, 12,13,14,15,16,17,18,19,20,21,22,23,24,25,27,28,29,30,31,36,45,52,56,63,68 ,72,78,83,93,99,102,10,88,110,117,118,129,131,134,151,156,162,165,169,184,191,196,19 8,210,216,227,248,256) to cover the total demand as shown in table 6.3, however, these locations can be narrowed down according to the suggestion that these terminals should be chosen to serve more than one airport at a time to increase its utilization, and to improve the economic viability.

Recalling the OAT locations [the locations that being repeated more than the others in each solution set] from table (6.1) and the airport's location on the map from Figure (6.8) we concluded Table (6.4) .

Figure (6.9) shows the best OAT locations that shared between more than one airport and at the same time provides the maximum coverage.

Table 6.4 the Preferred Location for the OAT

Airports	Best Location	No. of Iteration/Location
Newquay Cornwall Airport Exeter International Airport	13	9
Heathrow Airport Gatwick Airport London City Airport London Southend Airport Luton Airport Stansted Airport	44	8
Cardiff Airport Bristol Airport	50	4
Bournemouth Airport Southampton Airport	18	9
Birmingham International Airport East Midlands Airport Liverpool John Lennon Airport Manchester Airport Doncaster Sheffield Airport	117	9
Leeds Bradford International Airport Durham Tees Valley Airport	180	5
Belfast International Airport George Best Belfast City Airport	156	9
Glasgow Prestwick Airport Edinburgh Airport	207	4
Aberdeen Airport Inverness Airport	248	5

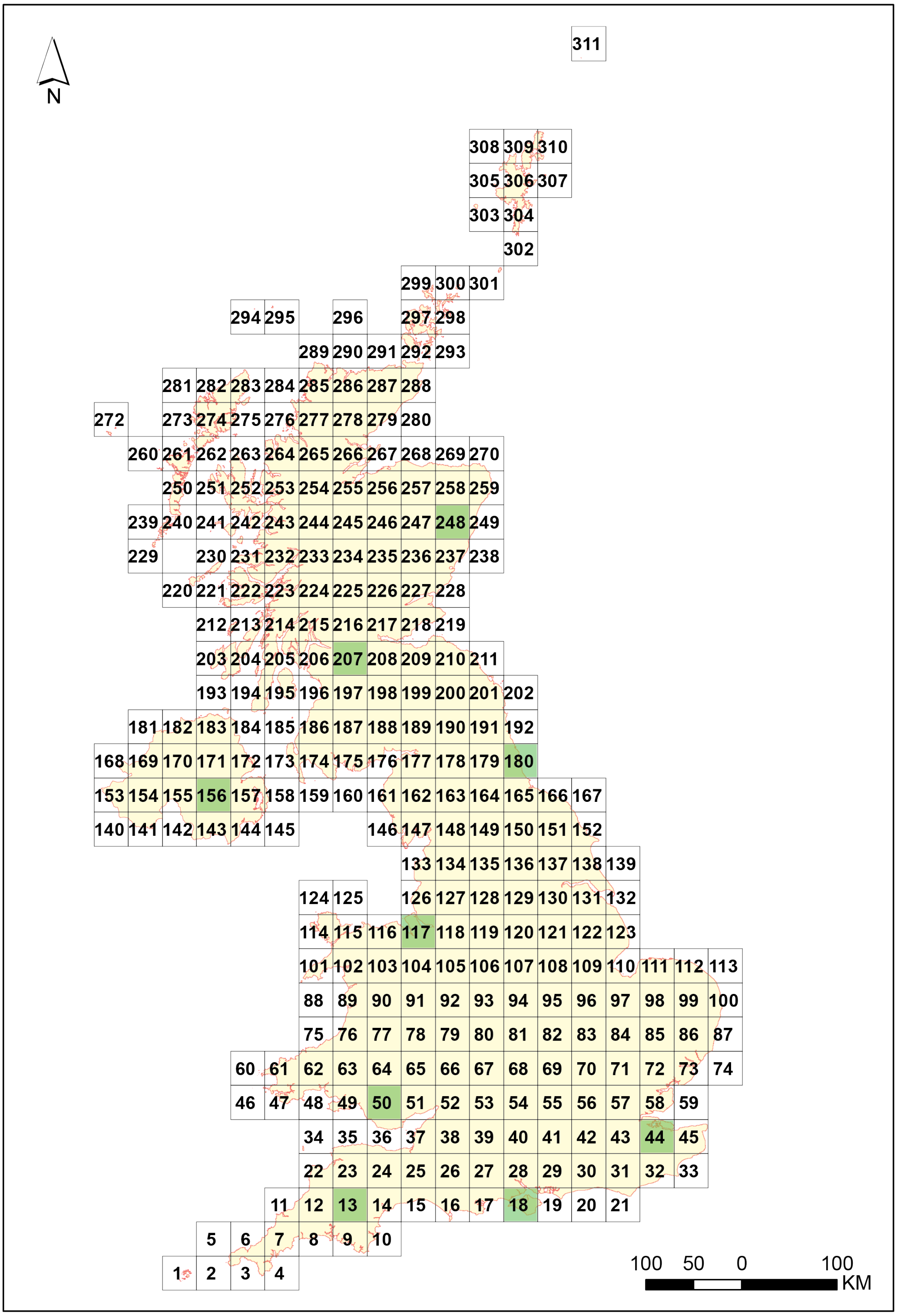

Figure 6.9 Map of the Preferred Location for the OAT

6.16 SUMMARY

The rapid growth of passenger volumes requires new business and operational models for processing passengers and baggage. Satellite Terminals (OFF-Airport terminals) can be a solution to effectively outsource the passenger and baggage processing functions from multiple terminals. The passengers passing through these terminals would be treated as transferring or transiting passengers at their actual departing and arriving airports. The best location for these terminals can be selected by prioritizing a list of candidate locations. However, in order to make these terminals economically viable, suitable business models are required to fund their development and operations.

CHAPTER 7

CONCLUSION

Many solutions have been proposed in literature to solve congestion problems at airports with the majority focused on change inside the airport terminal. Conversely, in this research the proposed solution to congestion problems at airport terminals has been focused on off-loading passengers and baggage processing outside the main airport. The main purpose of the research was to deliver the idea of complete baggage/passenger dissociation as a solution to congestion problems. For this service, the main drivers and challenges have been outlined, as well as presenting the idea of a new innovative baggage delivery network and off-airport terminal as two possible ways to implement the proposed concept. In the six chapters that formed the core of this project, answers to research questions formulated in the introduction have been presented. In this chapter, the answers that been obtained are presented in summary.

7.1 RESEARCH CONTRIBUTIONS

General background to air transport and airport services including a brief summary of the current challenges that facing the air transport industry has been presented, highlighting the congestion problem as the main issue that face many airports in the world nowadays. Therefore, the current research proposed a baggage dissociation concept as a contribution at the ground-side of the airport instead of focusing on the air-side and the runway parameters that have previously been studied by many researchers in the field. The primary objective was delivering the concept of baggage dissociation as a solution to the congestion problem at airport terminals. Taking in consideration data resource constraints, many of the required information is not publicly available and more difficult to obtain as they typically are proprietary and not disclosed by airlines or airports for business reasons. However, the key contribution of the research is to deliver the idea that the implementation of the dissociation concept is likely to be carried out in several phases which make it an open problem and subject to much research. The other contribution is finding methods that enable the implementation of this concept and two solutions have been suggested that can help to pave the way for the complete dissociation. The first one is the proposal that is inspired from the existing parcel delivery networks: Baggage Ground Distribution Networks, in which the baggage services (collect/drop-off) will take the bottleneck process out of the airport terminal. The second solution is the Off-Airport Terminals that can help with off-loading many services outside the airports. The last contribution is the aircraft performance analysis of 12 different aircraft that showed baggage weight is matter and by off-loading this weight the dissociation can be beneficial for airlines over the long term.

7.2 OBSTACLES AND ANTICIPATED BENEFITS OF THE DISSOCIATION CONCEPT

The widespread adoption of the baggage dissociation facing the following obstacles:

- In general, complete dissociation can only be considered at selected airports, on certain flight routes, or for some passengers. The current vision aims for a large scale adoption where the dissociation would become the norm rather than an extra service.

- New IATA rules are required to govern the dissociation whether it is implemented locally or at a large scale.

- There is a likely need for new infrastructure as well as to define the associated processes in order to enable the dissociation. This is likely to incur significant capital expenditures and further increase the system complexity.

- At present, there appears to be no economic analysis of the baggage dissociation. For instance, it is unclear how to cover the operational and capital costs (i.e., who would be paying for the new dissociation services), and whether these expenses would outweigh offered benefits. This implies that there is a need to develop new business models which can support and sustain the dissociation.

- Baggage dissociation could be completely outsourced to 3rd party providers who would then request baggage as a cargo (BaaC) delivery from the airline.
- Passengers may collect and drop off baggage at suitable points throughout the city. This creates additional handovers between the passengers and the couriers actually delivering baggage to the airport. This increases the complexity of the system as the handover of baggage ownership and accountability need to be clearly defined.
- The dissociation must be completed by reconciliation of the passengers with their luggage at any given point in time and space. This may turn out to be particularly difficult when the dissociation is enabled also in the air segment.
- Passenger expectations about the new dissociation services may be vastly different. For example, at present, it is unclear how much baggage reconciliation delay different types of passengers would be willing to tolerate.
- The dissociation will likely require careful advance planning. This may be severely disrupted by unpredictable changes in passenger travel plans, whether conscious or unintentional.
- The baggage dissociation and its independent delivery will affect other associated services such as customs at the destination country, and insurance to provide the agreed level of service.

However, the challenges of dissociation have to be balanced against the following anticipated benefits:

- Hassle free travel to and from the airports encourages the use of public transport which would relieve current curb-side congestion at many busy airports. This may also improve the passenger experience which is often stated as the main reason for considering the concept of baggage dissociation.

- The opportunity to develop new light, fast and fuel efficient aircraft which would reduce travel times by a large margin, and which can also reduce boarding and aircraft turn-around times at the gate.

- The opportunity to renovate airports with passenger only and baggage only terminals in order to improve their passenger and baggage handling capacity and efficiency.

- The opportunity to route baggage directly to the destination airports avoiding baggage transfers at intermediate hubs which is usually one of the most demanding baggage handling operations, and the main source of delayed or lost baggage.

- Reconsidering the baggage delivery as a expanded form of the current parcel delivery services which would remove the distinction between baggage and parcels. In this case, the baggage delivery would be truly independent from whether the passengers actually undertake the journey or not.

- Encouraging the use of public transport has enormous advantages. In addition to reducing the current curb-side congestion at many busy airports, it reduces air pollution, increases fuel efficiency, reduces traffic congestion and saves money.

- The infrastructure, processes and systems in Air Transport have not changed for over 40 years so they are dated as inefficient and complex. Therefore, the dissociation concept can make radical changes in this sector through renovating airport terminals to passenger only and baggage only in order to improve the capacity and the efficiency of passenger and baggage handling processes. Also, developing new light, fast and fuel efficient aircraft.

7.3 VALIDATION USING AIR TRANSPORT DATA

A lack of current and detailed data can be considered the main drawback of the current research. The evaluation of the baggage/passenger dissociation concept made use of real-life air transport data containing detailed flight information such as the exact number of passengers, weights, cost and revenue. Further research is required to validate and investigate how the proposed solution can meet the practical needs at airports. This investigation needs integrating and maximising the use of real-life data that can be collected from both airlines and airports.

7.4 EXTENSION OF THE PROPOSED FRAMEWORK

The scope of this research was limited to a single case study, Greater London, to establish the Baggage Ground Distribution Network and the UK, to assign the best locations of Satellite Terminals. Also, to evaluate extra revenue one set of 12 of the most common aircrafts has been used. Therefore, the future research activities can be expanded to investigate this concept in other cities and other busy airports. To analyse the cost and the revenue of operating this service through the airline network activity based costing needs to be applied. This requires the knowledge of the number of passengers that will use this service as well as the cost of the different activities that are required to deliver this service such as label printing, driving to/from the baggage distribution centers or the Off-Airport terminals to/from the airports, loading/unloading the aircraft etc….

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Appendix A.1

HEATHROW AIRPORT ARRIVALS

Flight Number	Type	Origin	Code	Departure	Arrival
BAW737	A319	Geneva Cointrin Int'l	GVA/LSGG	Sun 23:53 CEST	Mon 00:02 BST
BAW979	A319	Hanover/Langenhagen Int'l	HAJ/EDDV	Mon 00:46 CEST	Mon 00:48 BST
BAW16	B77W	Singapore Changi	SIN/WSSS	Sun 22:55 SGT	Mon 04:52 BST
BAW28	B77W	Hong Kong Int'l	HKG/VHHH	Mon 00:07 HKT	Mon 04:56 BST
BAW32	A388	Hong Kong Int'l	HKG/VHHH	Sun 23:34 HKT	Mon 04:32 BST
VIR207	B789	Hong Kong Int'l	HKG/VHHH	Mon 00:04 HKT	Mon 04:46 BST
BAW262	B772	King Khalid Int'l	RUH/OERK	Mon 00:50 AST	Mon 05:14 BST
BAW34	B789	Kuala Lumpur Int'l	KUL/WMKK	Sun 23:34 MYT	Mon 05:09 BST
BAW56	A388	OR Tambo Int'l	JNB/FAOR	Sun 20:14 SAST	Mon 05:42 BST
BAW64	B744	Jomo Kenyatta Int'l	NBO/HKJK	Sun 23:27 EAT	Mon 05:38 BST
BAW74	B772	Murtala Mohammed Int'l	LOS/DNMM	Sun 23:14 WAT	Mon 05:12 BST
CPA251	B77W	Hong Kong Int'l	HKG/VHHH	Mon 00:27 HKT	Mon 05:17 BST
UAL958	B763	Chicago O'Hare Intl	KORD	Sun 16:15 CDT	Mon 05:19 BST
AAL100	B77W	John F Kennedy Intl	KJFK	Sun 18:57 EDT	Mon 06:17 BST
AAL174	B763	Raleigh-Durham Intl	KRDU	Sun 18:00 EDT	Mon 06:21 BST
AAL50	B77W	Dallas-Fort Worth Intl	KDFW	Sun 16:06 CDT	Mon 06:33 BST
ACA822	A319	St. John's Int'l	CYYT	Sun 22:05 NDT	Mon 06:11 BST
ACA856	B77W	Toronto Pearson Int'l	CYYZ	Sun 18:48 EDT	Mon 06:15 BST
AIC161	B788	Indira Gandhi Int'l	DEL/VIDP	Mon 02:42 IST	Mon 06:56 BST
BAW106	B744	Dubai Int'l	DXB/OMDB	Mon 01:50 GST	Mon 06:05 BST
BAW112	B744	John F Kennedy Intl	KJFK	Sun 19:38 EDT	Mon 06:46 BST
BAW12	A388	Singapore Changi	SIN/WSSS	Mon 00:05 SGT	Mon 06:20 BST
BAW124	B772	Bahrain Int'l	BAH/OBBI	Mon 01:20 AST	Mon 06:12 BST
BAW1321	A319	Newcastle	NCL/EGNT	Mon 06:02 BST	Mon 06:52 BST
BAW160	B772	Shanghai Pudong Int'l	PVG/ZSPD	Mon 01:04 CST	Mon 06:10 BST

Appendix A.2

HEATHROW AIRPORT DEPARTURE

Flight Number	Type	Destination	Code	Departure (Sun)	ETA (Mon)	Arrival (Mon)
AIC116	B788	Indira Gandhi Int'l	DEL/VIDP	12:57 BST	00:53 IST	00:53 IST
BAW139	B77W	Chatrapati Shivaji Int'l	BOM/VABB	11:30 BST	00:15 IST	00:14 IST
BAW376	32A	Toulouse-Blagnac	TLS/LFBO	22:16 BST	00:27 CEST	00:27 CEST
BAW544	A321	Bologna (Guglielmo Marconi)	BLQ/LIPE	21:24 BST	00:04 CEST	00:04 CEST
BAW884	A321	Bucharest Henri Coanda Int'l	OTP/LROP	19:43 BST	00:27 EEST	00:20 EEST
FIN996	A321	Helsinki-Vantaa	HEL/EFHK	19:57 BST	00:12 EEST	00:12 EEST
QTR8	B77W	Hamad Int'l	DOH/OTHH	16:33 BST	00:24 AST	00:24 AST
SAS534	B736	Stockholm-Arlanda	ARN/ESSA	21:23 BST	00:19 CEST	00:22 CEST
UAE2	A388	Dubai Int'l	DXB/OMDB	14:39 BST	00:26 GST	00:25 GST
BAW155	B763	Cairo Int'l	CAI/HECA	19:49 BST	01:04 EET	01:04 EET
ETD20	A388	Abu Dhabi Int'l	AUH/OMAA	15:47 BST	01:15 GST	01:10 GST
UAE30	A388	Dubai Int'l	DXB/OMDB	17:23 BST	02:36 GST	02:35 GST
AVA121	A332	El Dorado Int'l	BOG/SKBO	22:57 BST	03:03 COT	03:03 COT
BAW35	B788	Chennai Int'l	MAA/VOMM	13:42 BST	03:40 IST	03:40 IST
BAW634	A320	Athens Int'l Eleftherios Venizelos	ATH/LGAV	22:14 BST	03:15 EEST	03:15 EEST
IRA710	A306	Imam Khomeini Int'l	IKA/OIIE	17:41 BST	03:01 IRDT	03:01 IRDT
RBA98	B788	Dubai Int'l	DXB/OMDB	18:07 BST	03:27 GST	03:27 GST
THY1984	A321	Istanbul Ataturk Int'l	IST/LTBA	22:37 BST	03:49 EEST	03:43 EEST
AFL2585	A333	Sheremetyevo Int'l	SVO/UUEE	23:14 BST	04:46 MSK	04:45 MSK
AIC130	B788	Chatrapati Shivaji Int'l	BOM/VABB	14:45 BST	04:04 IST	04:04 IST
BAW83	B772	Nnamdi Azikiwe Int'l	ABV/DNAA	23:26 BST	05:06 WAT	04:57 WAT
MEA204	A320	Beirut Air Base /Rafic Hariri Int'l (Beirut Int'l)	BEY/OLBA	22:18 BST	04:27 EEST	04:32 EEST
MSR780	B738	Cairo Int'l	CAI/HECA	22:51 BST	04:00 EET	04:08 EET
SIA305	A388	Singapore Changi	SIN/WSSS	09:42 BST	04:53 SGT	04:52 SGT

SVA116	777	King Abdulaziz Int'l	JED/OEJN	21:07 BST	04:35 AST	04:36 AST
BAW119	B772	Bengaluru Int'l	BLR/VOBL	15:14 BST	05:02 IST	05:01 IST
BAW163	B77W	Ben Gurion Int'l	TLV/LLBG	23:18 BST	05:30 IDT	05:30 IDT
BAW247	B744	Sao Paulo-Guarulhos Int'l	GRU/SBGR	22:51 BST	05:58 BRT	05:58 BRT
BAW277	B788	Rajiv Gandhi Int'l	HYD/VOHS	16:09 BST	05:26 IST	05:26 IST
ELY318	B772	Ben Gurion Int'l	TLV/LLBG	23:13 BST	05:24 IDT	05:11 IDT
TAM8085	B773	Sao Paulo-Guarulhos Int'l	GRU/SBGR	22:38 BST	05:29 BRT	05:33 BRT
THA911	A388	Suvarnabhumi Bangkok Int'l	BKK/VTBS	12:54 BST	05:41 ICT	05:41 ICT
VIR651	A333	Murtala Mohammed Int'l	LOS/DNMM	23:10 BST	05:22 WAT	05:10 WAT
BAW133	B788	King Abdulaziz Int'l	JED/OEJN	22:41 BST	06:17 AST	06:17 AST
BAW157	B744	Kuwait Int'l	KWI/OKBK	23:15 BST	06:52 AST	06:52 AST
CPA252	B77W	Hong Kong Int'l	HKG/VHHH	12:47 BST	06:46 HKT	06:39 HKT
GFA6	A332	Bahrain Int'l	BAH/OBBI	22:26 BST	06:35 AST	06:25 AST
PIA788	B772	Jinnah Int'l	KHI/OPKC	18:49 BST	06:34 PKT	06:34 PKT
QTR16	B788	Hamad Int'l	DOH/OTHH	22:24 BST	06:16 AST	06:16 AST
QTR2	A333	Hamad Int'l	DOH/OTHH	22:06 BST	06:23 AST	06:23 AST
SAA235	A343	OR Tambo Int'l	JNB/FAOR	19:28 BST	06:58 SAST	06:58 SAST
UAE4	A388	Dubai Int'l	DXB/OMDB	21:16 BST	06:41 GST	06:41 GST
AHY8	B788	Heydar Aliyev Int'l	GYD/UBBB	22:52 BST	07:26 AZST	07:26 AZST
BAW1382	A319	Manchester	MAN/EGCC	06:54 BST	07:45 BST	07:45 BST
BAW17	B788	Incheon Int'l	ICN/RKSI	13:15 BST	07:27 KST	07:21 KST
BAW7	B77W	Tokyo Int'l (Haneda)	HND/RJTT	12:26 BST	07:23 JST	07:01 JST
EIN149	A320	Dublin Int'l	DUB/EIDW	06:59 BST	08:07 IST	07:50 IST
PIA786	B77W	Islamabad Int'l/Chaklala Airbase	ISB/OPRN	20:18 BST	07:58 PKT	07:58 PKT
QFA2	A388	Dubai Int'l	DXB/OMDB	22:10 BST	07:18 GST	07:18 GST
SIA317	A388	Singapore Changi	SIN/WSSS	11:43 BST	07:04 SGT	07:03 SGT

BAW737	A319	Geneva Cointrin Int'l	GVA/LSGG	Sun 23:53 CEST	Mon 00:02 BST
BAW979	A319	Hanover/Langenhagen Int'l	HAJ/EDDV	Mon 00:46 CEST	Mon 00:48 BST
BAW16	B77W	Singapore Changi	SIN/WSSS	Sun 22:55 SGT	Mon 04:52 BST
BAW28	B77W	Hong Kong Int'l	HKG/VHHH	Mon 00:07 HKT	Mon 04:56 BST
BAW32	A388	Hong Kong Int'l	HKG/VHHH	Sun 23:34 HKT	Mon 04:32 BST
VIR207	B789	Hong Kong Int'l	HKG/VHHH	Mon 00:04 HKT	Mon 04:46 BST
BAW262	B772	King Khalid Int'l	RUH/OERK	Mon 00:50 AST	Mon 05:14 BST
BAW34	B789	Kuala Lumpur Int'l	KUL/WMKK	Sun 23:34 MYT	Mon 05:09 BST
BAW56	A388	OR Tambo Int'l	JNB/FAOR	Sun 20:14 SAST	Mon 05:42 BST
BAW64	B744	Jomo Kenyatta Int'l	NBO/HKJK	Sun 23:27 EAT	Mon 05:38 BST
BAW74	B772	Murtala Mohammed Int'l	LOS/DNMM	Sun 23:14 WAT	Mon 05:12 BST
CPA251	B77W	Hong Kong Int'l	HKG/VHHH	Mon 00:27 HKT	Mon 05:17 BST
UAL958	B763	Chicago O'Hare Intl	KORD	Sun 16:15 CDT	Mon 05:19 BST
AAL100	B77W	John F Kennedy Intl	KJFK	Sun 18:57 EDT	Mon 06:17 BST
AAL174	B763	Raleigh-Durham Intl	KRDU	Sun 18:00 EDT	Mon 06:21 BST
AAL50	B77W	Dallas-Fort Worth Intl	KDFW	Sun 16:06 CDT	Mon 06:33 BST
ACA822	A319	St. John's Int'l	CYYT	Sun 22:05 NDT	Mon 06:11 BST
ACA856	B77W	Toronto Pearson Int'l	CYYZ	Sun 18:48 EDT	Mon 06:15 BST
AIC161	B788	Indira Gandhi Int'l	DEL/VIDP	Mon 02:42 IST	Mon 06:56 BST
BAW106	B744	Dubai Int'l	DXB/OMDB	Mon 01:50 GST	Mon 06:05 BST
BAW112	B744	John F Kennedy Intl	KJFK	Sun 19:38 EDT	Mon 06:46 BST
BAW12	A388	Singapore Changi	SIN/WSSS	Mon 00:05 SGT	Mon 06:20 BST
BAW124	B772	Bahrain Int'l	BAH/OBBI	Mon 01:20 AST	Mon 06:12 BST
BAW1321	A319	Newcastle	NCL/EGNT	Mon 06:02 BST	Mon 06:52 BST
BAW160	B772	Shanghai Pudong Int'l	PVG/ZSPD	Mon 01:04 CST	Mon 06:10 BST

Appendix B

ICAO & IATA AIRCRAFTS CODES

AIRCRAFT CODES AND TYPES

ICAO	IATA	Aircraft Type
-	32A	Airbus A320 (with Sharklets)
-	32B	Airbus A321 (with Sharklets)
-	727	Boeing 727
-	73F	Boeing 737 frighter
-	747	Boeing 747
-	74F	Boeing 747 freighter
-	74H	Boeing 747-8i
-	74N	Boeing 747-8F
-	75T	Boeing 747-100 Freighter
-	767	Boeing 767
-	777	Boeing 777
-	787	Boeing 787
-	JST	British Aerospace Jetstream 31/32/41
A109	AGH	Agusta Westland A109
A124	A4F	Antonov AN-124 Ruslan
A140	A40	Antonov AN-140
A148	A81	Antonov An-148
A158	A58	Antonov An-158
A225	A25	Antonov An-225 Mriya
A306	ABY	Airbus A300-600
A30B	AB3	Airbus A300
A310	310	Airbus A310
A318	318	Airbus A318
A319	319	Airbus A319
A320	320	Airbus A320
A321	321	Airbus A321
A330	330	Airbus A330
A332	332	Airbus A330-200
A333	333	Airbus A330-300
A338	338	Airbus A330-800
A339	339	Airbus A330-900
A340	340	Airbus A340
A342	342	Airbus A340-200
A343	343	Airbus A340-300
A345	345	Airbus A340-500
A346	346	Airbus A340-600
A350	350	Airbus A350
A358	358	Airbus A350-800
A359	359	Airbus A350-900
A35K	351	Airbus A350-1000[2]
A388	388	Airbus A380-800
A3ST	ABB	Airbus A300-600ST Beluga Freighter
A748	HS7	Hawker Siddeley HS 748
AA5	-	Gulfstream American AA-5
AC11	-	Rockwell Commander 112, 114
AC50	-	Rockwell Commander 500
AC68	ACP	Gulfstream/Rockwell (Aero) Commander
AC90	ACT	Gulfstream/Rockwell (Aero) Turbo Commander
AC95	-	Rockwell Commander 695

AEST	-	Piper PA-60 Aerostar
AN12	ANF	Antonov AN-12
AN24	AN4	Antonov AN-24
AN26	A26	Antonov AN-26
AN28	A28	Antonov AN-28
AN30	A30	Antonov AN-30
AN32	A32	Antonov AN-32
AN72	AN7	Antonov AN-72 / AN-74
AP22	-	Aeroprakt A-22 Foxbat / A-22 Valor / A-22 Vision
AS32	APH	Eurocopter AS332 Super Puma
AS50	NDE	Eurocopter AS350 Écureuil / AS355 Ecu-reuil 2 / AS550 Fennec
ASTR	-	IAI 1125 Astra
AT43	AT4	Aerospatiale/Alenia ATR 42-300 / 320
AT45	AT5	Aerospatiale/Alenia ATR 42-500
AT46	ATR	Aerospatiale/Alenia ATR 42-600
AT72	AT7	Aerospatiale/Alenia ATR 72
AT73	ATR	Aerospatiale/Alenia ATR 72-200 series
AT75	ATR	Aerospatiale/Alenia ATR 72-500
AT76	ATR	Aerospatiale/Alenia ATR 72-600
ATL	ATL	Robin ATL
ATP	ATP	British Aerospace ATP
B06	-	AB-206 JetRanger/LongRanger
B105	MBH	Eurocopter (MBB) Bo.105
B190	BEH	Beechcraft 1900
B212	BH2	Bell 212
B350	-	Beech B300 Super King Air 350
B36T	-	Beech 36 Bonanza
B407	-	Bell Helicopter 407

B412	BH2	Bell 412
B429	BH2	Bell 429
B430	-	Bell Helicopter 430
B461	141	BAe 146-100
B462	142	BAe 146-200
B463	143	BAe 146-300
B703	703	Boeing 707
B712	717	Boeing 717
B712	717	Boeing 717
B720	B72	Boeing 720B
B721	721	Boeing 727-100
B722	722	Boeing 727-200
B731	731	Boeing 737-100
B732	732	Boeing 737-200
B732	73L	Boeing 737-200 combi
B732	73M	Boeing 737-200 combi
B733	733	Boeing 737-300
B734	734	Boeing 737-400
B735	735	Boeing 737-500
B736	736	Boeing 737-600
B737	73G	Boeing 737-700
B738	738	Boeing 737-800
B738	7S8	Boeing 737-800
B739	739	Boeing 737-900
B741	741	Boeing 747-100
B742	742	Boeing 747-200
B743	743	Boeing 747-300
B744	744	Boeing 747-400
B748	748	Boeing 747-8

Appendix C

AIRCRAFTS PERFORMANCE

Code	Type	Cargo_kg	Seats_ typical	Seats_ HD	Max_fuel_L	Range_max_payload_km
32A	Airbus A320-200	18600	150	180	23860-29840	5350-5550
32B	A321	23400	185	220	24050-30030	7400
74H	74H	76300	467	609	243400	14800
74N	74N	76067	467	605	238610	14430
767	767-200	33270	181	255	63220	9400
B767	767-200	33270	181	255	63220	9400
B767	767-200ER	35560	281	255	91380	12200
B77F	Freighter	103000	N/A	N/A	181283	9200
B738	737-800	20540	160	189	26020	5400
A306	A300-600R	39700	266	361	68160	7700
A30B	A30B	37495	266	345		6667
A310	A310-200	33550	187	279	54920	4000
A310	A310-300	33460	187	279	75470	5600
A318	A318-100	13300	107	117	23860	2750 - 6000
A319	A319	29840	124	156	24210	6900
320	A320-200	18600	150	180	23860 - 29840	5350 - 5550
A320	A320-200	18600	150	180	23860 - 29840	5350 - 5550
A321	A321	23400	185	220	24050-30030	7400
A330	A330 -200	49500	253	406	139000	12499
A332	A330-200	49500	247	406	139090	13450
A333	A330-300	51700	295	400	139090	10501

A342	A342	43500	300	420	155000	14800
A343	A343	50900	295	440	141500	13100 - 13500
A345	A345	54100	313	440	214800	15750 - 16400
340	A340-600	67200	380	440	194880	13900 - 14800
A346	A340-600	67200	380	440	194880	13900 - 14800
A358	A350-800	12950	280	440	138000	15400
A359	A350-900	16000	325	440	141000	15000
A35K	A350-1000	20890	366	440	156000	14800
A388	A380	83000	550	700	310000	15000
AC50	AC50	487	4	7		1915
AC90	AC90	811	6	8		3852
AC95	AC95	272	6	8		3852
AEST	AEST	931	4	5		2150
ASTR	ASTR	1072	9	11		5763
AT43	ATR 42-320	4600	44	50	5730	1130
AT45	AT45	5450	44	50	5730	1500
AT72	ATR 72-500	7350	62	81	6400	1330 - 1650
AT76	AT76	7500	68	78		1528
ATP	ATP	6640		64	6360	1824
B06	B06	907	6			630
B190	Beech 1900C	2200	19		2520	1070
B190	Beech 1900D	2920	19		2520	2733
B407	B407	1160	6			550
B461	B461	6650	70	79	11728	2174
B462	B462	8075	79	85		2909

B463	B463	9500	79	100		2181
B712	717-200 HGW	14500	106	134	16670	3800
B712	717-200	12000	106	134	13900	2600
B722	B722	18300	131	149	37020	3500
B732	737-200 Advanced	15700	102	130	19500	2090 - 2960
B733	737-300	15000	128	149	23830	2300 - 2900
B734	737-400	18260	146	171	23830	2500 - 3500
B735	737-500	14770	108	132	23830	3400
B736	737-600	14380	108	132		5650
B737	B737-300	15000	128	149	23830	5463
737	B737-800	20540	160	189	26020	7408
B738	B737-800	20540	160	189	26020	7408
B739	737-900	20240	177	215	26030	5080
B739	737-900	20240	177	189	26030	5080
B739	B739 737-900ER	525 m3	85	215	29660	5900
B744	747-400	70620	416	660	204340 - 216840	11440 - 13430
B744	747-400ER	67 900	416	660	228250 - 241140	13900 - 14200
B748	747-8	76300	467	467	243400	14800
B752	B752	25970	168	239	43490	5550
B753	757-300	31600	243	279	43400	6400
B762	767-200	33270	181	255	63220	9400
B762	767-200ER	35 560	181	255	91380	12200
B763	B767-300	40230	269	328	63200	9700
B763	B767-300ER	43800	269	328	91380	11000
B764	767-400	47000	245	375	91 380	10400

777	777-200R	50850	305	440	202500	15040 - 17450
B77L	777-200R	50850	305	440	202500	15040 - 17450
B772	777-200R	50850	305	440	202500	15040 - 17450
B772	777-200ER	51250	305	440	171170	10750 - 14300
B773	B777-300	66050	396	550	171170	7500 - 11000
B77W	777-300 ER	68500	396	550	181283	11390 -14600
787	787-8	41440	242	359	124700	14500
B788	787-8	41440	242	359	124700	14500
B789	B 787-9	60395	290	406	138700	15370
BE10	BE10	855	6	13		2484
BE20	BEECH 200 Super Ki	1820	7	15		3300
BE30	BE30	231	6	14	2100	3630
BE33	BE33	478	4		190	1648
BE35	BE35	487	4		148	1648
BE36	BE36	434		4	281	1648
BE40	BE40	985	6	8		1622
BE55	BE55	755	6		379	2276
BE58	BE58	621		5		1746
BE65	BE65	850	6	9	875	2441
BE80	BE80	984	6	11	1000	2441
BE99	BE99	1632	8	15		1687
BE9L	BE9L	1124	6	8		2484
BE9T	BE9T	1062	8	13		2484
C10T	C10T	426	5		330	1972
C152	C152	247	1			769

C172	C172	405		4	201	1272
C182	C182	445	1	3		1078
C206	C206	332	5		247	1335
C210	C210		5			1972
C25A	Citation CJ2	680	7	8	1782	2687
C25B	C25B	894	9	9		969
C25C	C25C	757	9	9	2221	3298
C30	Bombardier Challenge	1587	8	16		5741
C310	C310	528	4		387	1170
C340	C340	285	5		387	774
C402	C402	1260		9		2360
C404	C404	1360	9	10	1350	2800
C414	C414	421	5	8	387	2459
C421	C421	1338	6	8	807	2752
C425	C425	725	4	6	1386	2919
C441	C441	1039	9			4245
C501	C501	951	6			2459
C510	C510	539	4	5		2161
C525	Citation Jet/Citation C	640		7		2871
C550	C550	1270		8	2267	3701
C560	C560	1048	7	11		3297
C56X	C56X	3674		12	3057	3441
C60	Canadair/ CL-600 Cha	8391	18			6356
C650	C650	907	6	11	27956	4352
C680	C680	650		12		5926

C750	C750	621		12	7291	5956
CL35	CL35	817		10		6093
COL3	COL3	499	3		387	2584
COL4	COL4	340	3			2315
CRJ	CRJ100 ER	4540	50	79	5300	1800
CRJ1	CRJ100ER	4540	50	79	5300	1800
CRJ2	CRJ2 LR	6210		50	8080	3148
CRJ7	CRJ7	8530	66	78	10990	2650
CRJ700ER	CRJ700ER	8530	66	77	10990	3200
CRJ700R	CRJ700R	9070	66	77	10990	3700
CRJ9	CRJ9	10 590	76	90	10990	2500
CVLT	CVLT	7257	52			1980
D328	D328	3538	33			1852
DA40	DA40	324	3		155	2006
DA42	DA42	620	3			2222
DH8A	Bombardier Dash 8 Q	8750	70	84	6530	2500
DH8C	Dash 8-100	4100	37	79	3160	1900
DH8C	Dash 8-200	4200	37	79	3160	1700
DH8D	DH8D series 300	8670	68	90	6616	
DC-10	DC-10-10	40600	250	380	82 100	6100
DC-10	DC-10-30	45700	250	380	10 000	138700
DC-10	DC-10-40	65000	250	380		9200
E110	E110	1560		19	1670	1960
E120	E120	2930		30		1750
E135	E135 R	4499	37		6480	3100

E145	E145	5200	50		1670 US	2000
E170	AR	9840	70	80	11840	3100
E190	E190	12700	98	106	16250	3334
E35L	E35L	2355	37		10400	3232
E45X	ERJ-145LR	6100		50	6 480	2780
E50P	E50P	755	5	7	1272	2182
E55P	Embraer Phenom 300	1095	6	10	2428	3650
EA50	EA50	1089	4	5		2084
EC30	EC30	1500	6	7		644
EC35	EC35		6	7		665
F100	F100	12000	107	107	13 360	3 100
F2TH	F2TH	2500	8	10		6020
F70	Fokker 70	10890	79	85	13360	3470
F900	F900	1415	12	19		7840
FA10	FA10	1070	7			3560
FA20	FA20	2494		12		3300
FA50	FA50	1664	8	9		6297
FA7X	FA7X	1996	12	19		11019
G150	G150	635	6	8		5463
G280	G280	1840	10			6667
GL5T	GL5T	3238	13	13		9630
GLEX	GLEX Global 5000	3238	13	13		9630
GLEX	GLEX Global 6000	2617	13	13		11112
GLF2	GLF2	2184	12	19		6578
GLF3	GLF3	2812	11	19		6760

GLF5	GLF5	2812	13	19		10742
H25C	H25C	1043	15			6375
HA4T	HA4T	635	8	12		5287
HDJT	HDJT	293	4	6		2234
J328	J328	3266	30	33		1667
JS31	JS31	1837	19			780
JS32	JS32	2020		19		1260
LJ31	LJ31	1037	6	8		3076
LJ35	LJ35	1352		8	2811	5015
LJ40	LJ40	1036	8		3400	5015
LJ45	LJ45	856		9		3795
LJ55	LJ55	635	11			4156
LJ60	LJ60	951		8		4461
LJ70	LJ70	1036	8			3815
M20P	M20P	299	3		230	1220
M20T	M20T	340	3			1220
MD11	MD11	85000	285	410	146170	12270
MD80	MD-82	17400	144	168		3800
MD82	MD82	17400	144	168	22100	3800
MD83	MD83	16600	144	168	26350	4600
MD88	MD88	16600	144	168	22100	3800
MD90	MD90-30	17800	153	172	22130	386
MU2	MU2	620	6	7	1378	2584
P180	P180	816	9			3187

P28A	P28A	289		3	137	1185
P28R	P28R	91		3	250	1185
P32R	P32R	238	5	6	405	1756
P46T	P46T	158	5		644	1852
PA27	PA27	918	3	5	546	1141
PA31	PA31	748	5	7	568	1870
PA32	PA32	458	5	7		1361
PA34	PA34	294	4	5		
PA44	PA44	663		3	409	1630
PA46	PA46	234		6		1852
PAY1	PAY1	723	5	7		1556
PAY2	PAY2	650	5	7		1556
PC12	PC12	1400	9		1520	2500
PRM1	PRM1	635		6		2519
R22	R22	108	1			593
R44	R44	340	2	3	120	560
RJ1H	Avro RJ100	9500	79	100	11728	2255
RJ85	BAe Avro RJ85	8075	79	85	11728	2531
S76	S76		12	13		748
SB20	SB20	5500		50	5980	2100
SBR1	SBR1	975	10			4447
SF34	SAAB-340B	3880	37		3220	1500
SH36	SH36	3180	39		2180	1100
SR20	SR20	467		4		1422
SR22	SR22	605		4	348	1943

SU9	SU9	12250	95	98		3050
SW3	SW3	1944	8	11		3589
SW4	SW4	2540		19		2065
T154	Tu-154B-2	18000	81	180		2780
T154	Tu-154M	18000	81	180	39750	3900
TBM7	TBM7	758	5	6		3032
TBM8	TBM8	625	5	6		3032
WW24	WW24	1474	10		5500	4430

APPENDIX D

AIRPORT INFORMATION

IATA	ICAO	Airport	City	Country	ISO_country	ISO_region	Continent	Time zone	Type
HIR	AGGH	Honiara International	Honiara	Solomon Islands	SB	SB-CT	OC	11	medium
POM	AYPY	Port Moresby Jacksons International	Port Moresby	Papua New Guinea	PG	PG-NCD	OC	10	large
KEF	BIKF	Keflavik International	Reykjavík	Iceland	IS	IS-2	EU	0	large
RKV	BIRK	Reykjavik	Reykjavik	Iceland	IS	IS-1	EU	0	medium
YAM	CYAM	Sault Ste Marie	Sault Ste Marie	Canada	CA	CA-ON	NA	-5	medium
YBL	CYBL	Campbell River	Campbell River	Canada	CA	CA-BC	NA	-8	medium
YBR	CYBR	Brandon Municipal	Brandon	Canada	CA	CA-MB	NA	-6	medium
YCC	CYCC	Cornwall Regional	Cornwall	Canada	CA	CA-ON	NA	-5	medium
YCD	CYCD	Nanaimo	Nanaimo	Canada	CA	CA-BC	NA	-8	medium
YCE	CYCE	James T. Field Memorial Aerodrome	Centralia	Canada	CA	CA-ON	NA	-5	medium
XCM	CYCK	Chatham Kent	Chatham-Kent	Canada	CA	CA-ON	NA	-4	small

YCL	CYCL	Charlo	Charlo	Canada	CA	CA-NB	NA	-4	medium
YDF	CYDF	Deer Lake	Deer Lake	Canada	CA	CA-NL	NA	-4	medium
YEG	CYEG	Edmonton International	Edmonton	Canada	CA	CA-AB	NA	-7	large
YEL	CYEL	Elliot Lake Municipal	Elliot Lake	Canada	CA	CA-ON	NA	-5	medium
YEM	CYEM	Manitoulin East Municipal	Manitowaning	Canada	CA	CA-ON	NA	-5	medium
YFC	CYFC	Fredericton	Fredericton	Canada	CA	CA-NB	NA	-4	medium
YTM	CYFJ	La Macaza / Mont-Tremblant International Inc	Rivière Rouge	Canada	CA	CA-QC	NA	-5	medium
YGK	CYGK	Kingston Norman Rogers	Kingston	Canada	CA	CA-ON	NA	-5	medium
YGQ	CYGQ	Geraldton Greenstone Regional	Geraldton	Canada	CA	CA-ON	NA	-5	medium
YGR	CYGR	Îles-de-la-Madeleine	Îles-de-la-Madeleine	Canada	CA	CA-QC	NA	-4	medium
YHM	CYHM	John C. Munro Hamilton International	Hamilton	Canada	CA	CA-ON	NA	-5	medium
YHU	CYHU	Montréal / Saint-Hubert	Montréal	Canada	CA	CA-QC	NA	-5	medium
YHZ	CYHZ	Halifax / Stanfield International	Halifax	Canada	CA	CA-NS	NA	-4	large
YJT	CYJT	Stephenville	Stephenville	Canada	CA	CA-NL	NA	-4	medium

YKA	CYKA	Kamloops	Kamloops	Canada	CA	CA-BC	NA	-8	medium
YKF	CYKF	Waterloo	Kitchener	Canada	CA	CA-ON	NA	-5	medium
YLK	CYLS	Barrie-Orillia (Lake Simcoe Regional)	Barrie-Orillia	Canada	CA	CA-ON	NA	-5	small
YLW	CYLW	Kelowna International	Kelowna	Canada	CA	CA-BC	NA	-8	medium
YMM	CYMM	Fort McMurray	Fort McMurray	Canada	CA	CA-AB	NA	-7	medium
YMW	CYMW	Maniwaki	Maniwaki	Canada	CA	CA-QC	NA	-5	small
YMX	CYMX	Montreal International (Mirabel)	Montréal	Canada	CA	CA-QC	NA	-5	medium
YND	CYND	Ottawa / Gatineau	Gatineau	Canada	CA	CA-QC	NA	-5	medium
YOO	CYOO	Oshawa	Oshawa	Canada	CA	CA-ON	NA	-5	medium
YOW	CYOW	Ottawa Macdonald-Cartier International	Ottawa	Canada	CA	CA-ON	NA	-5	large
YPS	CYPD	Port Hawkesbury	Port Hawkesbury	Canada	CA	CA-NS	NA	-4	medium
YPN	CYPN	Port Menier	Port-Menier	Canada	CA	CA-QC	NA	-5	medium
YPQ	CYPQ	Peterborough	Peterborough	Canada	CA	CA-ON	NA	-5	medium
YQA	CYQA	Muskoka	Muskoka	Canada	CA	CA-ON	NA	-5	medium

YQB	CYQB	Quebec Jean Lesage International	Quebec	Canada	CA	CA-QC	NA	-5	large
YQG	CYQG	Windsor	Windsor	Canada	CA	CA-ON	NA	-5	medium
YQI	CYQI	Yarmouth	Yarmouth	Canada	CA	CA-NS	NA	-5	medium
YQK	CYQK	Kenora	Kenora	Canada	CA	CA-ON	NA	-6	medium
YQM	CYQM	Greater Moncton International	Moncton	Canada	CA	CA-NB	NA	-4	medium
YQR	CYQR	Regina International	Regina	Canada	CA	CA-SK	NA	-6	medium
YQS	CYQS	St Thomas Municipal	St Thomas	Canada	CA	CA-ON	NA		medium
YQT	CYQT	Thunder Bay	Thunder Bay	Canada	CA	CA-ON	NA	-5	medium
YQU	CYQU	Grande Prairie	Grande Prairie	Canada	CA	CA-AB	NA	-7	medium
YQX	CYQX	Gander International	Gander	Canada	CA	CA-NL	NA	-4	medium
YQY	CYQY	Sydney / J.A. Douglas McCurdy	Sydney	Canada	CA	CA-NS	NA	-4	medium
YQY	CYQY	Sydney / J.A. Douglas McCurdy	Sydney	Canada	CA	CA-NS	NA	-4	medium
YQY	CYQY	Sydney / J.A. Douglas McCurdy	Sydney	Canada	CA	CA-NS	NA	-4	medium
YQY	CYQY	Sydney / J.A. Douglas McCurdy	Sydney	Canada	CA	CA-NS	NA	-4	medium

YRQ	CYRQ	Trois-Rivières	Trois-Rivières	Canada	CA	CA-QC	NA		medium
YRT	CYRT	Rankin Inlet	Rankin Inlet	Canada	CA	CA-NU	NA	-6	medium
YSB	CYSB	Sudbury	Sudbury	Canada	CA	CA-ON	NA	-5	medium
YSC	CYSC	Sherbrooke	Sherbrooke	Canada	CA	CA-QC	NA	-5	medium
YSJ	CYSJ	Saint John	Saint John	Canada	CA	CA-NB	NA	-4	medium
YCM	CYSN	Niagara District	St Catharines	Canada	CA	CA-ON	NA	-5	medium
YTA	CYTA	Pembroke	Pembroke	Canada	CA	CA-ON	NA	-5	medium
YTS	CYTS	Timmins/Victor M. Power	Timmins	Canada	CA	CA-ON	NA	-5	medium
YTZ	CYTZ	Billy Bishop Toronto City Centre	Toronto	Canada	CA	CA-ON	NA	-5	medium
YUL	CYUL	Montreal / Pierre Elliott Trudeau International	Montréal	Canada	CA	CA-QC	NA	-5	large
YUL	CYUL	Montreal / Pierre Elliott Trudeau International	Montréal	Canada	CA	CA-QC	NA	-5	large
YUL	CYUL	Montreal / Pierre Elliott Trudeau International	Montréal	Canada	CA	CA-QC	NA	-5	large
YUL	CYUL	Montreal / Pierre Elliott Trudeau International	Montréal	Canada	CA	CA-QC	NA	-5	large
YUY	CYUY	Rouyn Noranda	Rouyn-Noranda	Canada	CA	CA-QC	NA	-5	medium

Appendix E

LCCARRIERS

LOW-COST-CARRIERS (LCCS) BASED ON ICAO DEFINITION

Airline name	ICAO	IATA	Region	Country	Start	Ceased
1time Airline	RNX	T6	Africa	South Africa	2004	2012
Air Arabia Egypt	RBG	E5	Africa	Egypt	2010	
Air Arabia Maroc	MAC	3O	Africa	Morroco	2009	
Air Leisure	ALD	AL	Africa	Egypt	2015	
Air Peace	APK	P4	Africa	Kenya	2016	
Atlas Blue	BMM	8A	Africa	Morroco	2004	2009
Aviator Aviation	AVV	T9	Africa	Egypt	2016	
Fastjet	FTZ	FN	Africa	Tanzania	2012	
Five Forty Aviation	FFV	5H	Africa	Kenya	2009	
Jambojet		JX	Africa	Kenya	2014	2017
Jet4you	JFU	8J	Africa	Morroco	2006	2012
kulula.com	CAW	MN	Africa	South Africa	2001	
Mango Airlines	MNO	JE	Africa	South Africa	2006	
Namibia Flyafrica	NMD	N6	Africa	South Africa	2015	
Safair	SFR	FA	Africa	South Africa	2014	
Skywise Airline	SWZ	C9	Africa	South Africa	2015	2015
9 Air	JYH	AQ	Asia and Pacific	China	2015	
Adam Air	DHI	KI	Asia and Pacific	Indonesia	2002	2008
Aero Asia International	RSO	E4	Asia and Pacific	Pakistan	1993	1997
Air Asia	AXM	AK	Asia and Pacific	Malaysia	1996	
Air Asia India	IAD	I5	Asia and Pacific	India	2014	
Air Asia Japan	WAJ	JW	Asia and Pacific	Japan	2012	2013

Air Asia X	XAX	D7	Asia and Pacific	Malaysia	2007	
Air Asia Zest	EZD	Z2	Asia and Pacific	Philippines	1995	2016
Air Blue	ABQ	PA	Asia and Pacific	Pakistan	2004	
Air Busan	ABL	BX	Asia and Pacific	Republic of Korea	2008	
Air Do	ADO	HD	Asia and Pacific	Japan	1998	
Air India Express	AXB	IX	Asia and Pacific	India	2004	
Air Manas	MBB	ZM	Asia and Pacific	Kyrgyzstan	2013	
Air Pegasus	PPL	OP	Asia and Pacific	India	2015	2016
Air Seoul	ASV	RS	Asia and Pacific	Republic of Korea	2016	
Cebgo	SRQ	DG	Asia and Pacific	Philippines	1995	
Cebu Pacific Air	CEB	5J	Asia and Pacific	Philippines	1996	
Chengdu Airlines	UEA	EU	Asia and Pacific	China	2010	
China West Air	CHB	PN	Asia and Pacific	China	2007	
Citilink	CTV	QG	Asia and Pacific	Indonesia	2001	
Compass Airlines		YM	Asia and Pacific	Australia	1990	1993
Eastar Jet	ESR	ZE	Asia and Pacific	Republic of Korea	2007	
Freedom Air	FOM	SJ	Asia and Pacific	New Zealand	1995	2008
GoAir	GOW	G8	Asia and Pacific	India	2005	
Golden Myanmar Airlines	GMR	Y5	Asia and Pacific	Myanmar	2013	
Hong Kong Express Airways	HKE	UO	Asia and Pacific	China (Hong Kong SAR)	2004	
Impulse Air		VQ	Asia and Pacific	Australia	1992	2004
IndiGo	IGO	6E	Asia and Pacific	India	2006	
Indonesia Air Asia	AWQ	QZ	Asia and Pacific	Indonesia	1999	
Jeju Air	JJA	7C	Asia and Pacific	Republic of Korea	2005	
JetKonnect	JLL	S2	Asia and Pacific	India	2014	
Jetstar	JST	JQ	Asia and Pacific	Australia	2003	

Jetstar Asia Airways	JSA	3K	Asia and Pacific	Singapore	2004	
Jetstar Japan	JJP	GK	Asia and Pacific	Japan	2012	
Jetstar Pacific Airlines	PIC	BL	Asia and Pacific	Vietnam	1991	
Jin Air	JNA	LJ	Asia and Pacific	Republic of Korea	2008	
Kingfisher Red	KFR	IT	Asia and Pacific	India	1995	2011
Kiwi Travel International Airlines	KIC	KC	Asia and Pacific	New Zealand	1994	1996
Lion Air	LNI	JT	Asia and Pacific	Indonesia	2000	
Lucky Air	LKE	8L	Asia and Pacific	China	2016	
Malindo Air	MXD	OD	Asia and Pacific	Malaysia	2012	
Mihin Lanka	MLR	MJ	Asia and Pacific	Sri Lanka	2007	
Nok Air	NOK	DD	Asia and Pacific	Thailand	2004	
NokScoot Airlines	NCT	XW	Asia and Pacific	Thailand	2015	
Oasis Hong Kong Airlines	OHK	O8	Asia and Pacific	China (Hong Kong SAR)	2005	2008
ONE-two-GO	OTG	OX	Asia and Pacific	Thailand	2003	2007
Pacific Blue	PBN	DJ	Asia and Pacific	New Zealand	2003	2011
PAL Express	GAP	2P	Asia and Pacific	Philippines	2008	
Peach Aviation	APJ	MM	Asia and Pacific	Japan	2012	
Philippines Air Asia	APG	PQ	Asia and Pacific	Philippines	2012	
Ruili Airlines	RLH	DR	Asia and Pacific	China	2013	
Scoot	SCO	TZ	Asia and Pacific	Singapore	2012	
SEAir International	SGD	XO	Asia and Pacific	Philippines	2012	
Skymark Airlines	SKY	BC	Asia and Pacific	Japan	1998	
Solaseed Air	SNJ	LQ	Asia and Pacific	Japan	2002	
SpiceJet	SEJ	SG	Asia and Pacific	India	2000	
Spring Airlines	CQH	9C	Asia and Pacific	China	2004	
Spring Airlines Japan	SJO	IJ	Asia and Pacific	Japan	2014	
StarFlyer	SFJ	7G	Asia and Pacific	Japan	2002	

Tasman Express		NZ	Asia and Pacific	New Zealand	2003	defunct
Thai AirAsia	AIQ	FD	Asia and Pacific	Thailand	2003	
Thai AirAsia X	TAX	XJ	Asia and Pacific	Thailand	2014	
Thai Lion Air	TLM	SL	Asia and Pacific	Thailand	2013	
Thai VietJet Air	TVJ	VZ	Asia and Pacific	Thailand	2015	
Tiger Airways Australia	TGG	TT	Asia and Pacific	Australia	2007	
Tigerair Mandala	MDL	RI	Asia and Pacific	Indonesia	2011	2014
Tigerair Singapore	TGW	TR	Asia and Pacific	Singapore	2003	
Tigerair Taiwan	TTW	IT	Asia and Pacific	Taiwan Province of China	2014	
TruJet	TRJ	2T	Asia and Pacific	India	2015	
T'way Airlines	TWB	TW	Asia and Pacific	Republic of Korea	2004	
V Australia	VAU	VA	Asia and Pacific	Australia	2009	2011
ValuAir	VLU	VF	Asia and Pacific	Singapore	2004	2005
Vanilla Air	VNL	JW	Asia and Pacific	Japan	2013	
VietJet Air	VJC	VJ	Asia and Pacific	Vietnam	2011	
Virgin Australia	VOZ	VA	Asia and Pacific	Australia	2000	
Virgin Samoa	PBN	DJ	Asia and Pacific	Samoa	2005	
Viva Macau	VVM	ZG	Asia and Pacific	China (Macau SAR)	2005	2010
Wings Air	WON	IW	Asia and Pacific	Indonesia	2003	
AB Airlines			Europe	United Kingdom	1992	1999
Aer Arann	REA	RE	Europe	Ireland	1970	2014
Aeris		SH	Europe	France	1990	2003
Air Europe			Europe	Italy	1988	2008
Air Polonia		4P	Europe	Poland	2001	2004
Air Scotland			Europe	United Kingdom	2002	2006
Air Service Plus			Europe	Italy	2003	defunct
Air Southwest	WOW	WO	Europe	United Kingdom	2003	2011

Appendix F

LONDON POPULATION

Cell No.	Pop
1	4023
2	4474
3	2263
4	3382
5	1
6	72
7	185
8	412
9	823
10	21700
11	25051
12	4850
13	6221
14	4831
15	871
16	793
17	18210
18	6448
19	61304
20	49872
21	49635

22	25268
23	23599
24	9875
25	23242
26	390
27	145
28	56509
29	50343
30	70798
31	40584
32	109361
33	52102
34	39666
35	32162
36	45028
37	775
38	1125
39	18038
40	29004
41	57976
42	32294
43	84195

44	118772
45	82686
46	72930
47	62313
48	39236
49	30258
50	4035
51	0
52	22391
53	51667
54	60966
55	26439
56	34191
57	96305
58	123664
59	89602
60	82608
61	83917
62	40912
63	54618
64	30962
65	10167

66	1822
67	8948
68	61423
69	56478
70	56736
71	63804
72	157014
73	138425
74	163228
75	118273
76	72571
77	74129
78	75468
79	57997
80	19277
81	19188
82	44625
83	77166
84	67194
85	77712
86	109168
87	160961

88	86399	112	12800	136	80645	160	34
89	92967	113	349	137	64180	161	107
90	137250	114	0	138	69007	162	726
91	83743	115	1465	139	75766	163	131
92	54998	116	22232	140	116576	164	1413
93	34836	117	62560	141	73373	165	20347
94	7760	118	65265	142	73267	166	10186
95	11990	119	59991	143	48596	167	35252
96	70	120	61778	144	26694	168	57802
97	21783	121	60075	145	25313	169	5578
98	36615	122	78012	146	36052	170	0
99	51086	123	140433	147	18508	171	531
100	59755	124	82467	148	395	172	2695
101	65776	125	101528	149	827	173	79
102	89828	126	59866	150	208		
103	154139	127	83073	151	2872		
104	135451	128	51069	152	17061		
105	178667	129	56231	153	15290		
106	144663	130	25365	154	33063		
107	107139	131	1652	155	59279		
108	159255	132	6382	156	64281		
109	91179	133	10729	157	70418		
110	63422	134	36422	158	33682		
111	38448	135	63885	159	1406		

Appendix G

THE UK POPULATION / CELL

Cell No.	Pop
1	2204
2	2537
3	57512
4	11011
5	266
6	96423
7	205636
8	82842
9	319203
10	153056
11	25719
12	62197
13	57486
14	336963
15	57565
16	126680
17	501986
18	267714
19	289501
20	139860
21	184552
22	40806
23	107827
24	91547
25	254722
26	163459
27	148320
28	684423
29	381094
30	667859
31	313802
32	231703
33	98812
34	131
35	20571
36	140322
37	291905
38	782906
39	187070
40	234426
41	962278
42	2377259
43	1438239
44	679692
45	410024
46	0
47	51300
48	31718
49	439956
50	716833
51	590075
52	439378
53	319865
54	411270
55	565647
56	3961773
57	3078405
58	688929
59	0
60	33
61	41011
62	67738
63	56885
64	27559
65	129182
66	289141
67	269300
68	216643
69	455026
70	735020
71	257392
72	379686
73	366232
74	0
75	10703
76	43731
77	20645
78	62148
79	285189

80	848697
81	626968
82	514764
83	310534
84	333111
85	178499
86	126902
87	20268
88	0
89	24679
90	33466
91	132383
92	334322
93	2156498
94	896511
95	321411
96	304240
97	158696
98	119818
99	358074
100	197931
101	19068

102	30175
103	16465
104	210480
105	405801
106	397137
107	1233022
108	231328
109	155454
110	107833
111	43621
112	89040
113	1371
114	35468
115	132889
116	154371
117	1109689
118	865489
119	330917
120	1105760
121	203818
122	144180
123	82520

124	4653
125	705
126	826785
127	2065203
128	1210120
129	1075736
130	298381
131	266297
132	11828
133	464680
134	423457
135	758236
136	824991
137	156081
138	389633
139	1909
140	191
141	11143
142	14567
143	98009
144	52266
145	0

146	6124
147	195754
148	29588
149	42646
150	97606
151	47694
152	125191
153	8269
154	64619
155	87632
156	205207
157	594894
158	9649
159	85
160	36
161	115552
162	35910
163	21362
164	110675
165	694831
166	86262
167	134

168	406
169	52824
170	50655
171	143652
172	165647
173	13858
174	13148
175	16714
176	26550
177	138995
178	23235
179	458912
180	1001685
181	95724
182	50404
183	82285
184	6551
185	543
186	11755
187	5379
188	64707
189	9399

190	4260
191	59917
192	185735
193	3
194	6399
195	5171
196	248124
197	59936
198	23828
199	53418
200	33631
201	27126
202	558
203	2725
204	980
205	7833
206	243855
207	1516039
208	308826
209	615348
210	27087
211	22071

212	54
213	193
214	8089
215	42028
216	83730
217	299732
218	209749
219	15412
220	240
221	528
222	1383
223	14852
224	1302
225	5247
226	85292
227	243862
228	41685
229	0
230	195
231	2620
232	3424
233	12548

234	905
235	5841
236	10244
237	53432
238	0
239	214
240	1942
241	14
242	3570
243	790
244	1443
245	3781
246	7571
247	7668
248	92504
249	217887
250	2231
251	1711
252	4204
253	3755
254	507
255	96829

256	29487
257	23809
258	38237
259	53535
260	0
261	1289
262	867
263	845
264	2428
265	2229
266	25530
267	11496
268	52563
269	14247
270	19145
271	0
272	0
273	28
274	2256
275	1462
276	510
277	589

278	1702
279	4636
280	0
281	20
282	2712
283	13007
284	55
285	1100
286	732
287	6065
288	12392
289	25
290	0
291	0
292	0
293	5891
294	4306
295	51
296	0
297	15866
298	988
299	678

300	429
301	68
302	334
303	0
304	14381
305	549
306	4906
307	74
308	0
309	0
310	440
	63183847

APPENDIX H

THE PYTHON SCRIPT

```
time operations ###

:(def rmdayfromtime(t1
“““remove day from time string if present“““
[‘?‘,‘days = [‘Mon’,’Tue’,’Wed’,’Thu’,’Fri’,’Sat’,’Sun
((()tm = list(map(str.strip,t1.split
if len(tm)==1: return t1
([:if tm[0] in days: return “ “.join(tm[1
else: return t1

:(def splittime(t1
[‘days = [‘Mon’,’Tue’,’Wed’,’Thu’,’Fri’,’Sat’,’Sun
()fr = t1.split
((fr = list(map(str.strip,fr
‘‘ = [if fr[0] == ‘?‘: fr[0
[‘if len(fr)==1: return [‘‘, fr, ‘UTC
:if len(fr)==2
(‘if fr[0] in days: fr.append(‘UTC
(‘‘,else: fr.insert(0
return fr

:(‘def convtime(t,fromtzhm,fromtzcode=‘‘,totzhm=’+00:00’,totzcode=’UTC
“““convert time from one TZ to another TZ“““
[‘days = [‘Mon’,’Tue’,’Wed’,’Thu’,’Fri’,’Sat’,’Sun
(fr = splittime(t
if not fr[2]: fr[2] = fromtzcode
da1,tm1,tz1 = fr
convert time to UTC #
(((‘:‘)ti = list(map(int,tm1.split
(((‘:‘)of1 = list(map(int,fromtzhm[1:].split
:‘+‘==[if fromtzhm[0
[ti[0] -= of1[0
[ti[1] -= of1[1
:else
[ti[0] += of1[0
[ti[1] += of1[1
convert time to target TZ #
(((‘:‘)of2 = list(map(int,totzhm[1:].split
:‘+‘==[if totzhm[0
[ti[0] += of2[0
[ti[1] += of2[1
:else
[ti[0] -= of2[0
[ti[1] -= of2[1
adjust time and day #
da2= da1
(if da1: di2 = days.index(da1
:if ti[1]<0
ti[1] += 60
ti[0] -= 1
:if ti[1]>=60
ti[1] -= 60
ti[0] += 1
```

```
:if ti[0]<0
ti[0] += 24
[if da1: da2 = days[(di2-1) % 7
:if ti[0]>=24
ti[0] -= 24
[if da1: da2 = days[(di2+1) % 7
:if da1
(return "{} {:02d}:{:02d} {}".format(da2,ti[0],ti[1],totzcode
:else
(return "{:02d}:{:02d} {}".format(ti[0],ti[1],totzcode

:('def cmptimes(t1,t2,tzhm1="+00:00",tzhm2="+00:00",dz='Mon
returns True if t1>=t2 i.e. t1 occurs after t2, and False other-"""
"""wise
['days1 = ['Mon','Tue','Wed','Thu','Fri','Sat','Sun
(i = days1.index(dz
[days = days1[i:] + days1[:i
(fr1 = splittime(t1
(fr2 = splittime(t2
[if not fr1[0]: fr1[0] = fr2[0
[if not fr2[0]: fr2[0] = fr1[0
[if not fr1[2]: fr1[2] = fr2[2
[if not fr2[2]: fr2[2] = fr1[2
make the comparison #
if fr1==fr2: return True
:[if fr1[0
if days.index(fr1[0])<days.index(fr2[0]): return False
if days.index(fr1[0])>days.index(fr2[0]): return True
(to1 = convtime("{} {}".format(fr1[1],fr1[2]),tzhm1
('.',':')tc1 = to1.split()[0].replace
(to2 = convtime("{} {}".format(fr2[1],fr2[2]),tzhm2
('.',':')tc2 = to2.split()[0].replace
(return float(tc1)>=float(tc2

:(def difftimes(t1,tzhm1,t2,tzhm2, units='h', hhmm=True
""" '[returns t1-t2 formatted as 'Day HH:MM:SS [TZ"""
{ conv = { 'h':1/60.0, 'min':1.0, 's':60.0, 'sec':60.0
['days1 = ['Mon','Tue','Wed','Thu','Fri','Sat','Sun
(fr1 = splittime(t1
(fr2 = splittime(t2
'if not fr1[0]: fr1[0] = fr2[0] if fr2[0] else 'Mon
'if not fr2[0]: fr2[0] = fr1[0] if fr1[0] else 'Mon
'' = [fr1[2] = fr2[2
calculate the difference #
(s1 = convtime(" ".join(fr1),tzhm1
(s2 = convtime(" ".join(fr2),tzhm2
()fr1 = s1.split
()fr2 = s2.split
([i = days1.index(fr2[0
[days = days1[i:] + days1[:i
(':')f1 = fr1[1].split
(':')f2 = fr2[1].split
\ ([dd = (days.index(fr1[0]))*24*60 + int(f1[0])*60 + int(f1[1
[days.index(fr2[0]))*24*60 + int(f2[0])*60 + int(f2[1])) # [min))-
:if hhmm
\ % "return "%c%02d:%02d
(if dd>=0 else '-',abs(dd) // 60, abs(dd) % 60 '+')
:else
```

```
[return round(dd * conv[units], 5) # [hours

:(def addtime(t,dt
"""add dt to time t"""
['days = ['Mon','Tue','Wed','Thu','Fri','Sat','Sun
(fr= splittime(t
:[if not fr[0
("print("this addition requires to specify the day
()exit
(':')f1 = fr[1].split
([t1 = int(f1[0])*60 + int(f1[1
(':')f2 = dt[1:].split
([t2 = int(f2[0])*60 + int(f2[1
if dt[0]=='-': t0 = t1 - t2
else: t0 = t1 + t2
([di = days.index(fr[0
:if t0<0
(t0 = 1440 - abs(t0
[da = days[(di-1) % 7
:elif t0>=1440
t0 -= 1440
[da = days[(di+1) % 7
[else: da = fr[0
(return "{0} {1:+03}:{2:02}".format(da,t0 // 60, t0 % 60

:('def gpsdist(c1,c2,units='nm
```