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## GLOSSARY OF TERMS

**Aircraft kilometres** are the distances flown by an aircraft. An aircraft's total flying is obtained by multiplying the number of flights performed on each flight sector by the sector distance.

**Aircraft Utilisation** is the average number of block hours that each aircraft is in use. This is generally measured on a daily or annual basis

**Available seat-kilometres (ASKs)** are obtained by multiplying the number of seats available for sale on each flight by the flight sector distance.

**Average aircraft capacity** is obtained by dividing an airline's total available tonne kilometres (ATKs) by aircraft kilometres flown.

**Average sector length** is obtained by dividing an airline's total aircraft kilometres flown in a year by the number of aircraft departures; it is the weighted average of sector/sector lengths flown by an airline.

**Block time (hours)** is the time for each sector flight or sector, measured from when the aircraft leaves the airport gate or stand (chocks off) to when it arrives on the gate or stands at the destination airport (chokes on). It can also be calculated from the moment an aircraft moves under it's own power until it comes to rest at its destination.

**Break-even load factor (percent)** is the load factor required to equate total traffic revenue with operating costs.

**Flight crew** refers to pilots, stewards and stewardesses.

**Operating costs per ATK** is a measure obtained by dividing total operating costs by total ATKs. Operating costs exclude interest payments, taxes and extraordinary items. They can also be measured per RTK.

**Passenger load factor (per cent)** is revenue passenger-kilometres (RPKs) expressed as a percentage of available seat kilometres (ASKs) on a single sector; this is simplified to a number of passengers carried as a percentage of seats available for sale.

**Slot** at an airport is the right to operate one take-off or landing at that airport within a fixed time period.
**Sector/sector distance** the air route or flying distance between two airports**.**

**Regulation:** This term is defined as a set of principles, rules or laws designed to control or govern conduct. In the airline industry, all air carriers and countries have set rules and regulations they are meant to adhere to according to international standards. The bodies set aside to govern and ensure this are the civil aviation agencies set up in most countries**.**

**Deregulation:** This is defined as the removal of government controls from an industry or sector, to allow for a free and efficient marketplace, which would encourage competition

**Liberalisation:** Liberalisation is the act of relaxing the laws governing an industry making them less strict or less severe.

**Privatisation:** If a government privatises an industry, company or service that it owns and controls, it sells it so that it becomes privately owned and controlled.

**Open skies:** These are agreements, which permit unrestricted service by the airlines of each side to, from and beyond the others territory, without restrictions on where carriers fly the number of flights they operate and the prices they charge.

# CHAPTER 1: INTRODUCTION

## 1.1 Background

In his study, Wolf (2001) states that the international air transport system has undergone substantial institutional changes in the last two decades. Since World War II, there has been domination of a dense network of bilateral air service agreements (ASAs) that contained (and typically still contain) tight regulations of market entry, fares and capacities. However, since the end of the 1970s, more air transport markets have been subject to liberalisation, either on a bilateral or on a multilateral intra-regional basis. The US government has signed liberal bilateral ('Open Skies') ASAs with a number of trading partners and intra-EU air transport has been completely liberalised since 1997. Furthermore, the last decade has seen a trend towards multilateral intra-regional liberalisation in other parts of the world, such as:

- South America (Andean Pact of 1991 and Fortaleza Agreement of 1997)
- Africa (Banjul Accord of 1997; CEMAC, COMESA and Yamoussoukro II, all of 1999)
- The Caribbean Community (1998)
- The South East Asian region (CLMV Agreement of 1998),
- The Middle East (Arab Civil Aviation Commission of 1998).

## 1.2 African Aviation Issues

The African aviation industry has faced many problems over the last three decades; the extent of these problems is due to the fact that this industry is very dynamic and its rules and regulations are standard worldwide. The strict monitoring of and required adherence to the institutional, technical and operational areas in the industry present problems for the African continent, as discussed below.

### 1.2.1 Institutional issues

The current crisis in Africa's civil aviation industry has been blamed on the absence of coherent air transport policies, excessive bureaucracy and bad management strategies (Akpoghomeh, 1999). Positive policies were thus needed to prevent the total collapse of most African national airlines, especially those in the West African sub-region. This was a result of the developments in the world aviation industry, such as deregulation within the EU and USA, privatisation of European airlines, the introduction of the global Computer Reservation System (CRS) and the imposition of noise-reduction standards for obsolete aircraft.

The biggest step taken by the African aviation industry was the meeting in Yamoussoukro, Ivory Coast, in October 1988 of African ministers responsible for civil aviation. The purpose of this meeting was to agree on how air transport should be used as an important instrument for social and economic development in Africa in general, and to integrate the continent into the current globalisation of the aviation industry. This heralded the historic Yamoussoukro Declaration (YD) of 1988 whose objectives included:

- To pursue cooperation in air transport through integration of airlines and through the strengthening of the existing cooperative structures and the creation of new entities
- To show more flexibility in the granting of Fifth Freedom rights to African airlines, while countries will exchange traffic rights among themselves and will formulate a common policy for the granting of traffic rights to carriers outside Africa

- To minimise operating costs and tariffs
- To improve the management of existing airlines
- To work towards the financing of air transport activities by establishing an African aircraft leasing and financing company
- To attempt to obtain for aircraft registered in Africa exemption from compliance with the current aircraft noise-restriction standards.

Since this meeting the Yamoussoukro Declaration has changed its name to the Yamoussoukro Decision. It has not been effectively implemented by African airlines or civil aviation authorities. Since most airlines operate under bilateral service agreements as agreed in the Chicago Convention of 1944, the fight to liberalise the African skies at country level has met with resistance. In spite of the slow progress, the Yamoussoukro Decision is a step in the right direction towards the development of the African civil aviation industry.

Civil aviation authorities, airport authorities and ministries in charge of air transport are struggling to maintain the standards of the aviation industry in accordance with the International Civil Aviation Organisation (ICAO), the governing body, whose role is discussed in Chapter 2.

### 1.2.2 Technical issues

Most of the commercial aircraft used on the African continent are not only very old, but also very poorly maintained. Moreover, most of them are no longer in use in either Europe or the USA as a result of the new noise regulations in force. This suggests that Africa has become a dumping ground for aircraft that are no longer useable in the developed countries of Europe and North America. Furthermore, there is no proper inspection, monitoring and control of the aviation industry.

In addition, since 2001 there has been an increasing trend of blacklisting of airlines, whereby the EU sends out lists of airline companies that should not be landing their aircraft in Europe and with whom no dealings should be had. As expected, Africa has borne the biggest brunt of this blacklisting exercise, with whole countries and many airlines being put on the list, to the point where ICAO has had to step in to take specific measures to ensure that this does not cripple the already struggling African aviation industry.

The safety of the African skies has also been an area of growing concern over the last few years. In 2005, according to the Aviation Safety Network, Africa was still the most unsafe continent, with 13 fatal accidents (37%), although the continent accounts for only approximately 3% of all world aircraft departures. A sign of concern is that the moving ten-year average trend shows an almost continuous increase in the average number of fatal accidents for the last 11 years: from an average of 5,1 accidents in 1993 to 8,4 accidents in 2005 (Flight Safety Foundation, 2005).

### 1.2.3 Operational issues

There are over 350 airlines registered in Africa, most of which do not operate and many of which do not have traffic rights to operate beyond the region, but operate on a small scale domestically and regionally due to lack of adequate aircraft. These airlines have suffered from the perennial management problems associated with the above-mentioned structural deficiency of the institutional frameworks, by which the airlines were run as government departments. In other words, government oversaw the activities of the airline and non-executive board members were appointed on political grounds. Consequently, the airlines played mainly a political and/or social role, rather than operating as viable airlines at a minimum social cost. This resulted in a lack of staff discipline, leading to flight cancellations, flight delays, poor on-board services, poor public relations and missing baggage. Delayed flights, for example, were associated with over-booking and ineffective control of passengers at check-in points, which were major causes of the congestion and the rather rowdy atmosphere at the nations' airports. In the wake of poor performance in terms of profit, most countries are now turning to privatisation of their national airlines.

The infrastructural facilities of most African airports are hugely insufficient in the light of new technological advances and the heightened security demands imposed on the industry after 9-11. In Nigeria, for example, infrastructural facilities were scanty and limited at almost all the airports, and so were improvised most of the time. For instance, smoke provided information on wind direction, dumb-bell signals indicated the direction for landing, while the responsibility for warnings on landing aircraft included human controllers. The smaller airports, such as Benin airport, had grass runways, which were frequently waterlogged at the peak of the rainy season, thereby rendering such airports unusable for several weeks (Akpoghomeh, 1999).

## 1.3 Problem Statement

The air transport industry has remained one of the most regulated and restrictive industries in international trade. Domestic deregulation and liberalisation have been progressing at an uneven pace across countries and liberalisation of the international markets has yet to overcome numerous obstacles. Air carriers, on the other hand, need to build up an extensive global network to realise economies of scope and density and to meet consumer demands (Oum et al., 2001).

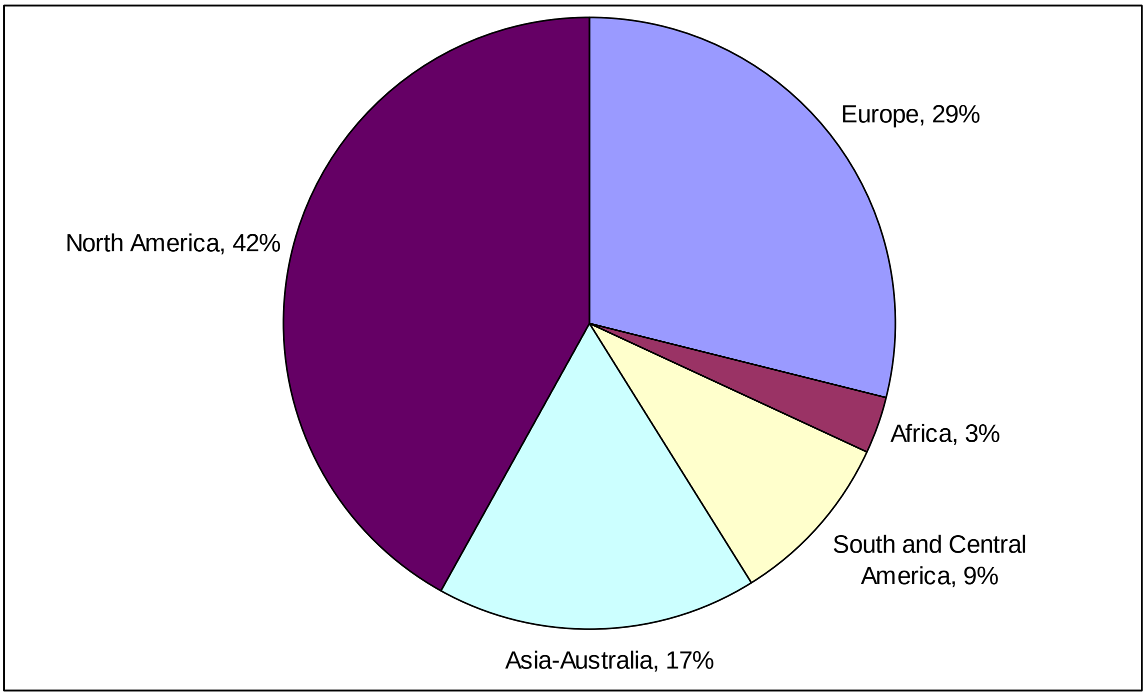
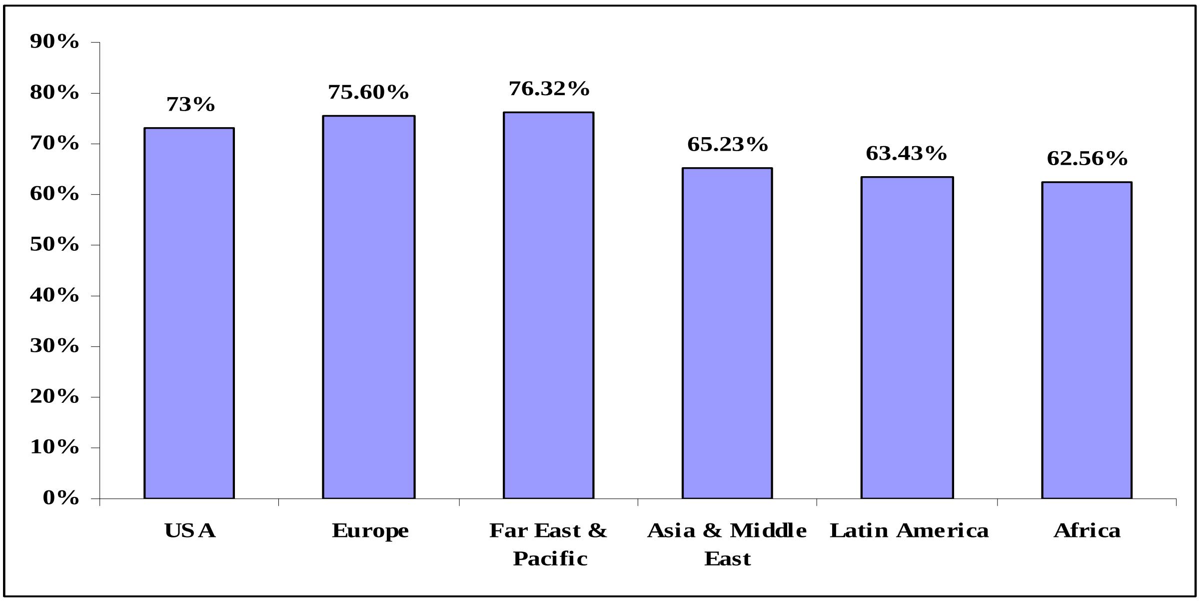



**Figure 1: Percentage of world air departures**

The sparse travel demand in Africa is shown in Figure 1, with Africa contributing only 3% (the smallest percentage) to world departures. Furthermore, the load factor, which is the ratio of the revenue passenger kilometres (RPK) to the available seat kilometres (ASK), is one of the critical determinants of profitability in relation to the break even load factor. Figure 2 shows that the African region has the lowest load factor at

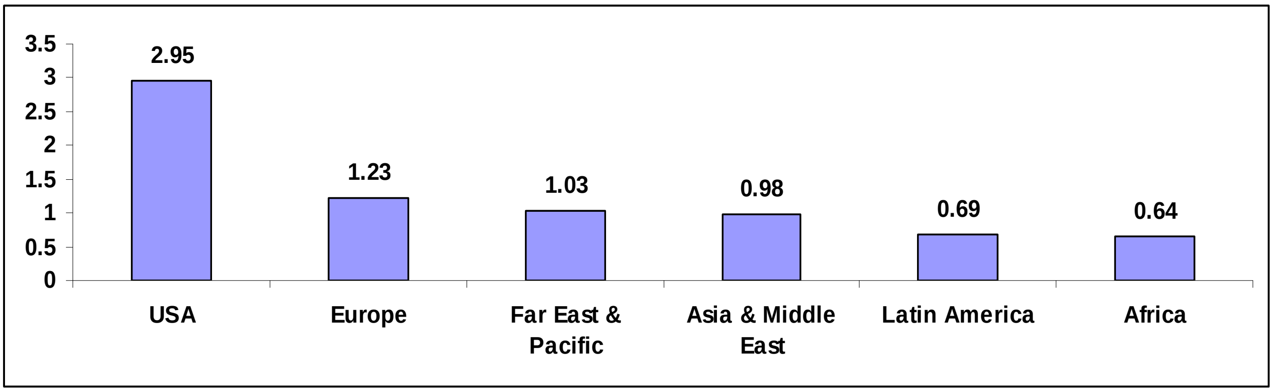
62.56%, compared with other regions of the world. The Far East and Pacific regions have relatively high load factors, averaging 76.32%. The low load factors are a reflection of the scanty routes in the African region. The routes are scanty because of the much higher air fares compared with those in other regions of the world and because of a relatively poor population, hence the sparse travel demand on the continent.




Source: Chingosho, 2005

**Figure 2: Load factors for world regions**

For many countries in Africa, the high-capital-intensive and low-profit-margin aviation industry is faced with numerous problems in trying to run efficient airline services. The elasticity of demand, with respect to fare, for all travellers is lowest in Africa and highest in the USA, as shown in Figure 3. This is a reflection of the limited options available to travellers within Africa (Chingosho, 2005).




Source: Chingosho, 2005

**Figure 3: Elasticity of demand for all travellers**

There is increasing pressure for government airlines in Africa to improve efficiency while making a profit in the face of issues such as privatisation, alliances with foreign airlines and more stringent aviation standards of security and noise. This implies that for liberalisation within African skies, as suggested by the Yamoussoukro Decision, an analysis needs to be done on the economics of an African regional airline. Some traditional airlines, such as South African Airways, Ethiopian Airlines and Kenya Airways, are actively pursuing expansion within the continent by providing direct flights for lucrative routes while hubbing at their home airports of Johannesburg, Addis Ababa and Nairobi respectively to consolidate passenger demand.

A hub-and-spoke (H&S) network should be investigated to ascertain whether this would be an economically viable option to serving all routes on the African continent, despite the low levels of passenger demand and long sector distances between countries.

## 1.4 Purpose of the Research

The purpose of this research is to investigate cost-effective strategies for designing an H&S network arrangement for air travel within Africa. The main purpose of the network would be to optimise the transport service for both the operator and the user in a bid to lower the costs of setting up a regional airline service.

There are two major parts to the study, namely:

1. Designing an optimum H&S network for a regional airline service to meet passenger demand, which will minimise costs.
2. Investigating whether the H&S network arrangement is a viable option for both the user and operator of an airline service, in terms of indicators such as costs, service frequency and time factors.

## 1.5 Justification

Button et al. (1999) define the hub and spoke as a network that entails a scheduled airline feeding into large airports, banks of flights that come from a variety of origins, and consolidating passengers onto outward flights to a range of destinations. Hubbing is a way in which airlines can save a lot of money, because hubbing reduces sector lengths and increases the number of passengers travelling over these short distances (Kane, 1996).

Wolf (2001) identifies one of the key features of the airline industry as the existence of route networks centering on one or a few hubs, which serve as interchange points for connecting traffic. Such networks enable airlines to exploit economies of scope and traffic density by consolidating traffic, thereby lowering the average costs of services on integrated routes. When designing their route networks, airlines prefer to locate hubs at airports that are centrally located in relation to the main traffic flow that the network serves.

Hubbing has both positive and negative effects on passenger demand because, on the negative side, there are time penalties as well as the disutility associated with making a connection rather than flying non-stop. On the other hand, hubbing can significantly reduce the passengers' schedule wait and add many origin-destination pairs to the network. Costs can be reduced due to higher traffic densities, but they are offset to varying degrees by the circuitous routings sometimes involved in hub operations (Hensher, 2002). The effects of hubbing, giving the positive and negative effects on unit cost, are shown in Table 1.

**Table 1: Effects of hubbing on cost of service**

| Positive | Negative |
|---|---|
| • Reduces the average sector distance flown, so shorter range aircraft with cheaper operating costs can be used.<br>• Intensive utilisation of aircraft and crews, operating more flight hours per day | • Additional passenger handling involved<br>• Places greater peak-load pressure on the hub airport<br>• Extra staff and handling equipment required for shorter time intervals |

Source: Hensher, 2002

There is significant evidence that consolidation of flows through hub airports can reduce movement costs through economies of density, even though the distance travelled may increase (Campbell, 1994; Hanlon, 1999). Yet, despite their dominance in many parts of the world, especially in the US and Europe (Button, 2002; Nigel, 2002), hub-and-spoke networks are by no means universal; nor is there agreement about their benefits (Schnell and Huschelrath, 2004; Hanlon, 1999). While there is "little doubt that it is good for the competitive position of the individual airline" (Hanlon, 1999:152), analysts point to the increased congestion and environmental costs at hub airports (e.g. Morrell and Lu, 2007) as negatives that are likely to affect the growth of hub-and-spoke operations in future (Schnell and Huschelrath, 2004). No other comparable source of data is accessible for the air transport market in other regions at affordable costs. Given that most of the experience with hub-and-spoke (H&S) strategies is from the more developed parts of the world, it is worth asking the question whether similar results can be obtained under different circumstances, and how benefits would compare with disbenefits.

This study will look at designing a cost-effective H&S network arrangement for Africa that will serve the present passenger demand from all countries and, thereafter, at making a comparison to test the effectiveness of hubbing within this vast continent for particular routes versus flying directly on the routes. The effects that will be compared are limited to quantifiable indicators such as time delays, operating costs and user costs that may affect either the service providers or the users of the service. This implies that information such as user opinions or preferences will not be taken into consideration.

## 1.6 Contribution to the Field

Some of the previous studies that are relevant to this research are listed below. These studies all highlight different aspects of the H&S arrangement, but what they have in common is that they all deal with high passenger demand networks.

- Abdulaziz (1994) focuses on sparse travel demands for domestic flights within one country with short sector distances.
- A general analysis and the effects of hubbing at different airports are given for Canberra International airport (Hensher, 2002) and Hamburg airport (Mandel & Schnell, 2001).
- Network analysis for hubbing within small regions is given for South-East Asia by Bowen (2000) and for domestic travel within Saudi Arabia by Abdulaziz (1994).

Andersson (2001) stresses that one of the central problems of sparsely populated regions is the combination of economies of scale and low accessibility levels. Sparsely populated regions have to cope with transportation system indivisibilities combined with low levels of demand that are insufficient to cover long-run transportation costs.

This study will look specifically at sparse travel demand in Africa in a less dense network, where sector distances may be considerably longer, thus challenging some of the typical benefits of the H&S network. An H&S network for existing passenger flow within Africa will also be designed and will include hub location, node allocation and network costing.

Some of the questions that will be answered in this study are:

1. What is the cheapest network design strategy that can be adopted for a vast continent with sparse travel demand?
2. When passenger demand is low and the route network less dense, are both the positive and negative effects of hubbing reflected?

3. Will the cost-benefit analysis of the H&S arrangement versus the direct route service for specific routes produce a higher return?

The results of the research will contribute to the understanding of the H&S network arrangement in relation to both the African situation, through the hub-location choices, and to cost-effective service design in general. On a broader scale, other potential sparse demand markets can use this study as a guideline for determining the feasibility of creating H&S networks in airline services where sector distances are high and passenger demand is low.

## 1.7 Objectives

The main objective of the research is to investigate the benefits and implications of a cheap hub network, in a market with sparse demand on the African continent. The specific objectives are:

1. To analyse the African aviation industry regulatory policies, in order to pave the way for faster liberalisation of the African skies
2. To understand the effects of creating an H&S network and to determine what different design methodologies are available
3. To develop an H&S network design methodology for Africa, which will minimise costs
4. To analyse the network results in order to understand the cost-effective strategies entailed in hub network design
5. To draw general conclusions about the applicability of an H&S network arrangement versus direct flights for typical routes within Africa.

## 1.8 Research Methodology

The following steps were involved in this study:

1. Collect, review and analyse the literature on the aviation industry in Africa, especially the steps taken in the Yamoussoukro Decision.
2. Collect and review literature relevant to creating H&S networks and the design methods used.
3. Design and cost an H&S network arrangement within Africa by:
    a. using an appropriate hub-location methodology to choose airport hubs within Africa.
    b. developing an allocation model to reassign all the links to hubs in order to minimise the costs of node-hub links
    c. calculating the total cost of routing all passengers through the different hub networks, from their origin to their destination.
4. Analyse the different H&S networks in terms of network, hub-hub and node-hub costs in order to design an H&S network for sparse travel demand in a less dense network, drawing conclusions on the positive and negative effects of network design for the service providers and the users.
5. Compare quantifiable indicators for typical routes in a hub network and then for a point-to-point network. The parameters include operating cost parameters based on demand for the routes, flight frequency, travel time and travel distance, and fleet size in the H&S networks versus direct flights

along the same routes. This was done by applying the operating cost model developed by Ssamula (2004), which calculates various cost indicators.

## 1.9 Organisation of the Thesis

This thesis consists of the following chapters:

1. Introduction

   This chapter gives an overview of the study, giving the background to the study, the problems addressed, specific objectives and the methodology followed.

2. Deregulating African Skies

   The policies, regulatory frameworks and implications regarding the deregulation of the aviation industry are studied, giving the history of policies on deregulation and liberalisation, with specific emphasis on the African continent and how it can open up its skies.

3. Hubbing Theory

   This chapter reviews all the available literature on hubs in the aviation industry. It highlights the relevant studies that have been done to show the effects of hubbing. Theories about various hub-location methods and hub network designs are summarised to show the way forward for designing hub networks.

4. Route Cost Model

   In this chapter the cost model that is used to calculate operating costs for running an airline service is described, with specific emphasis on the development of the cost equations and of a model to calculate operating costs of a route in Africa; the data used for the African scenario are referenced, compiled and validated. The cost model is used to reveal the economies of scale gained with consolidation of passengers.

5. Hub Network Design

   This chapter deals with the systematic procedure to be followed in creating a possible hub network, from the hub-location methods, to node allocation and lastly the costing of the final network. All the cost-effective methods are described in detail, with the justifications made for each methodology.

6. Results and Analysis

   The various networks that have been developed are analysed to give inferences as to how costs can be minimised in the design of an H&S network arrangement for the Africa-specific data.

7. Effectiveness of Hubbing

   This chapter deals with the effectiveness of a H&S network for typical routes as compared with direct flights for the Africa network.

8. Conclusions and Recommendations

   Finally, the conclusions drawn from the study are given, stating whether the aim of the study has been achieved, and recommendations are made as to further necessary research identified in this study.

# CHAPTER 2: DEREGULATING AFRICAN SKIES

## 2.1 Introduction

The regulatory policies framework and their implications regarding the deregulation of the aviation industry are studied in this chapter, giving the history of deregulation, liberalisation towards the open-sky with specific emphasis to the African continent. The relevance of this topic is that in order for regional airlines and H&S networks to be set up, the market needs to be liberalised.

The air transport industry has remained one of the most regulated and restrictive industries in international trade. Air carriers, in order to keep up with the current market trends, need to build up an extensive global network to realise economies of scope and density and to meet consumer demands. Deregulation and liberalisation have been progressing at an uneven pace across countries and liberalisation of the international markets has yet to overcome numerous obstacles.

This chapter deals with how the airline industry has evolved over the years, and how the restrictions on the airline industry have been reduced. Africa's steps towards deregulation are introduced and how they are being implemented. This will be used as a stepping-stone to propose various ways in which countries can participate in lifting barriers to improve the air transport industry in Africa.

## 2.2 The International Framework for Aviation Regulation

This section deals with the history of the rules and regulations that govern the international civil aviation industry. Aviation is one of the most regulated industries at a global level and the rules governing the industry are impartial to geographical location.

### 2.2.1 Paris Convention

The Convention for the Regulation of Aerial Navigation ("Paris Convention"), which was signed on October 13th 1919, is the pre-eminent multilateral agreement for the international aviation regime, evolving from the Paris Peace Conference of 1919 to set the foundation for regulation of the international airline industry. This convention recognised the need for every nation having "sovereignty" over the airspace above its territory, setting forth the fundamental policy, which underlies all aviation negotiations today.

### 2.2.2 Chicago Convention on International Civil Aviation

This convention on international civil aviation, commonly known as the "Chicago convention" was signed on 7$^{th}$ December 1944 by 52 states, while pending ratification on the convention by 26 states, the Provisional International Civil Aviation Organisation (PICAO) was established which functioned from the 6$^{th}$ June 1945 until 4$^{th}$ April 1947. By 5$^{th}$ march 1947, the 26$^{th}$ ratification was received and International Civil Aviation Organisation (ICAO) came into being on 4$^{th}$ April 1947. In October of the same year, ICAO became a specialised agency of the United Nations linked to the Economic and Social Council (ECOSOC). The purpose of this convention was to standardise and provide a regulatory framework for the air transport industry worldwide and the body ICAO was set-up to ensure this.

Some of the main outcomes of the Chicago convention, involved standardising different types of scheduled operations categorised according to the various 'freedoms of air'. Below we define the different freedoms and how they apply to an airline A of country A, given rights to fly into or over the territory of the grantor country B. These degrees of freedom, have since then been the basis, as to how much lee-way a country can give another in operating in their airspace

The ***first freedom*** is the right to fly and carry traffic non-stop over the territory of the grantor state, as illustrated 'First-freedom' rights would, for example, include that of carriers to over fly country B en-route to their final destinations, as shown in Figure 3.

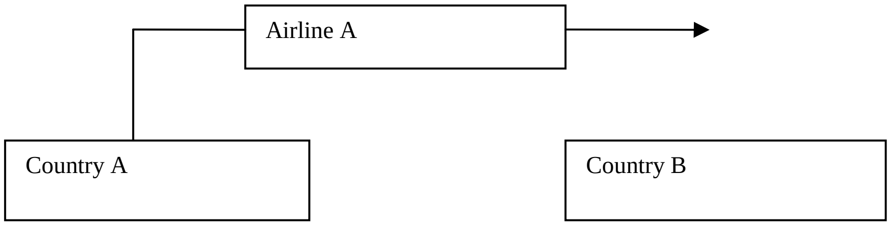



**Figure 3: First freedom**

The ***second freedom*** demonstrated in Figure 4 is the right to fly and carry traffic over the territory of the grantor state and to make one or more stops for non-traffic purposes. Before the availability of long-range aircraft this would for example have applied to transatlantic traffic that needed to make a refuelling stop at County B.

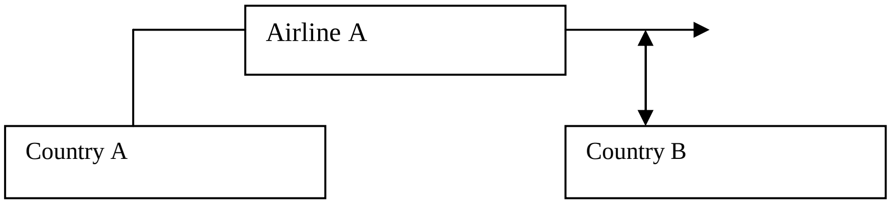



**Figure 4: Second Freedom**

The ***third freedom*** is the right to fly into the territory of the grantor state and set down traffic coming from the flag state of the carrier. This would apply to airlines in Country A carrying traffic from their country to Country B as their destination shown in Figure 5.

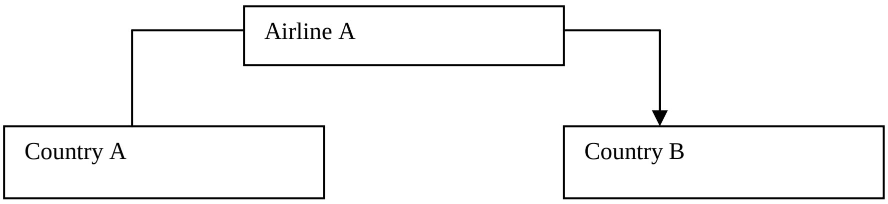



**Figure 5: Third Freedom**

The ***fourth freedom*** is the right to fly into the territory of the grantor state and take on traffic destined for the flag state of the carrier. This would apply to airlines in Country A carrying traffic from Country B to Country A, shown in Figure 6. The third and fourth freedoms are usually granted on a bilateral basis in the Airline Service Agreements (ASAs) between pairs of countries.

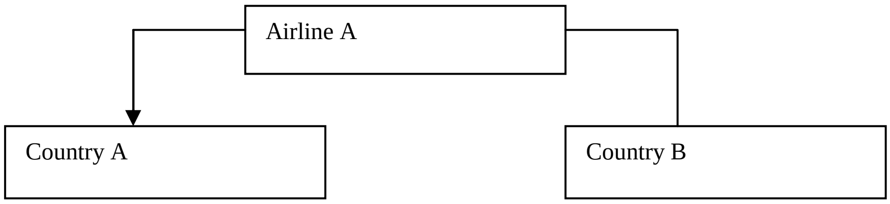



**Figure 6: Fourth Freedom**

The ***fifth freedom*** is the right to fly into the territory of the grantor state (country B) and take on or set down traffic to or from third states (Country C). This right is, however, confined to services which originate or terminate in the territory of the carrier's flag state (Country A) or which serve its flag state as an intermediate stop. The fifth-freedom right from B to C in the first of these cases is illustrated in Figure 7.

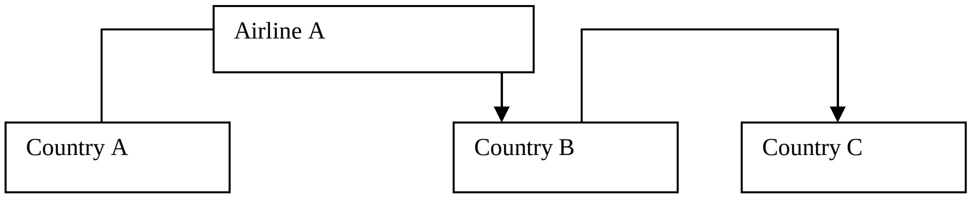



**Figure 7: Fifth Freedom**

For example Air India flies daily from New Delhi, India to London Heathrow, UK then picks up passengers and continues on to John F. Kennedy Airport, New York, USA.

The ***sixth freedom*** derives from the exercise of rights granted under the third and fourth freedoms and was not specified as such in the 1944 Agreement. Demonstrated in Figure 8, it is the right to fly into the territory of the grantor state (Country B) and take on (or set down) traffic for the carrier's flag state (Country A) which is subsequently carried to (or previously originated from) a third state (Country C) on a different service. Sixth freedom flights from B to C are illustrated below KLM, for example, carries sixth-freedom traffic between London and Toronto, passengers travelling from London to Amsterdam for a connecting flight from Amsterdam to Toronto.

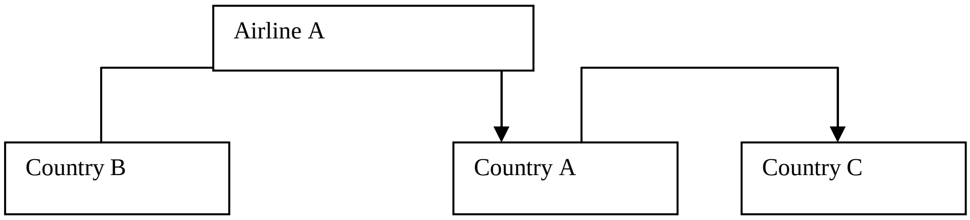



**Figure 8: Sixth Freedom**

Two further 'freedoms' are sometimes quoted, but are less frequently granted, except in the European Union..

The ***seventh freedom*** is the right for a carrier operating entirely outside the territory of its flag state, to take on or set down traffic in the grantor state for carriage to or from a third state. The US-EU open skies agreement entails the unilateral granting by the United States to the EU of so-called **"7th Freedom rights for Passengers"** to a number of non-EU European countries, i.e., the right for Community airlines to operate flights between a city in the United States and a city in these European countries

The ***eighth freedom*** referred to as 'cabotage' is the right for an airline of another state to carry traffic from one point in the territory of a state, to another point within the same state. Such rights have on occasion been granted when a country has a shortage of aircraft capacity. Neither the seventh nor the eighth 'freedom' was included in the 1944 Agreement.

These rights have been applied in some states as has been shown in the examples, but it needs to be highlighted that in order for deregulation to take place, it must involve liberalising these traffic rights. Different issues come into play with awarding of these rights as a way of states protecting themselves from competition from larger airlines, ensuring national security and limiting restrictions by Regional Integration Agreements (RIA).

## 2.3 Air Service Agreements (ASAs)

The last two decades have brought about significant changes for air transport, such that the regulatory framework under which airlines and airports operate has altered its character fundamentally, as a result of the liberalisation of major air transport markets in the world (Wolf, 2001). Airlines have adopted new strategies in response to these challenges. Some of the ASAs that have been liberalised today and the various ways are elaborated below to include their effects, applicability or sustainability in today's world.

### 2.3.1 Bilateral agreements

As aviation technology progressed, the need for additional aviation diplomacy became apparent. A bilateral agreement was the first step towards removing air barriers. This type of agreement between two countries permits air services only to those cities specified in the bilateral. Governments of both countries negotiate bilateral air transport agreements to determine items such as international airline routes, frequency and capacity. These agreements established a regulatory mechanism for the performance of commercial air services between the two countries.

Bilateral air transport agreements are generally made by executive agreements, treaties, or an exchange of diplomatic notes and are essentially reciprocal exchanges of authorisation to permit international air services between two contracting parties. For example, Britain and the US in 1946 negotiated a model bilateral air service agreement commonly known as Bermuda I, where by the United States agreed that international tariffs and fares would be set by the International Air Transport Association (IATA).

In exchange, Britain allowed US carriers to determine their passenger capacities and frequency of service. Additionally, the agreement provided for liberal fifth-freedom traffic rights for both parties which lasted for the next thirty years, but had to be renegotiated due to disagreements between the two countries as the industry changed over the years.

These agreements controlled air traffic flow between the partner countries by means of designation of air carriers that were allowed to serve routes, by controlling market access (which means defining traffic rights as well as landing points), by implementing controls for air services capacity and frequency and by regulating air fares. As long as the system of restrictive bilaterals governed almost all international air transport links worldwide, national governments had almost full control over all air traffic flow, to and from their own countries. They typically used their control measures to support their national airlines on international markets (Wolf, 2001).

In the European Union (EU) under the system of bilateral agreements there were very few non-competing airlines and no price competition. Markets were determined to advance both in terms of total market size and market shares while new market entrants were initially banned. Below are some of the effects of the bilateral agreements on the industry in the EU (Barrett, 2004):

1. European airfares were shown in ICAO surveys as the highest in the world.
2. Inadequate attention was paid to the costs of airlines both internally and externally.
3. Since no airlines competed on price, increases in costs were passed on to passengers by airlines acting jointly.
4. The high-cost national airlines enjoyed both regulatory capture over governments and "de facto" control over major airports.

5. Since most airlines were government-owned and the industry had low profit margins, the governments offered protectionism to their employees by offering high ratio of wages to GDP per head with low productivity.

As seen from some of the effects above, bilateral agreements facilitated the lack of agreement especially after the Chicago convention as to how the market for air services should be regulated, which ultimately led to the growth of bilateral agreements between countries. These were generally restrictive and they controlled market entry, fares and service levels thus protecting this service industry from foreign competitors. Since bilateral agreements were also made at government level, they promoted the growth of national carriers along the particular routes.

Although bilateral agreements continue to be conducted, criticisms of these bilateral agreements are that the system is no longer sound or sufficiently growth oriented in the global trade environment. The bilateral system is limited in its ability to encompass the broad multinational market access required by the new global operating systems (Edwards, 2002). Furthermore the bilateral system is under debate in the new aviation industry because this system has become an anti-competitive tool often used by governments for the protection of their national airlines. With the current trends in aviation industry focusing on globalisation, we need a system that will create competition and new opportunities for emerging airlines (Morrison, 2004). For example in the UK, the government's objective in the new transport policy of 1984, was to encourage a sound and competitive multi-airline industry with a variety of airlines of different characteristics serving the whole range of travellers needs and strong enough to compete aggressively against foreign airlines. Major airlines now operate on a global scale.

### 2.3.2 Deregulation and "liberalisation"

Deregulation is very much a US term, while in other parts of the world 'liberalisation' or 'regulatory reform' is the more common jargon. The birth of deregulation resulted from the Airline Deregulation Act (ADA), which was a piece of US legislation, signed into law on October 28$^{th}$ 1978. The main purpose of the act was to remove government control and open the domestic passenger air transport industry to market forces. The intention of the ADA was that with market forces determining the price, quantity and quality of domestic air service there would be a reduction in fares, lower barriers to entry for new airlines and the increased use of different aircraft for different roles (turboprop vs. jet engine). Deregulation therefore allowed for a free and efficient marketplace, which would encourage competition within the market. The act intended for the restrictions to be removed over four years with complete elimination of restrictions on domestic routes and new services by December 31$^{st}$ 1981 and the end of all domestic fare regulation by 1 January 1983 (Edwards, 2002).

The effects of deregulation in the US on the aviation industry from just the first decade after deregulation from 1978 to 1987 were shown as (Button et al., 2002):

- Passenger enplanements were up 55%
- Employment had risen from 340 000 to 450 000
- Scheduled passenger revenue miles were up 62%
- Seat availability was up 65%
- In terms of fares, deregulation allowed discount fares and 90% of travellers were using them by 1986 enjoying an average discount of 61%.

From the positive effects above, deregulation had transformed the aviation industry from a public utility to a modern business making the industry more competitive. The airline industry shows a lot of amicability to the free market more generally because the airlines make more money by flying longer journeys. The high aircraft capital costs are spread per hour utilised and there is a maximum limit to which an aircraft can fly especially with bilateral agreements and domestic travel. In operating cost terms, the more destinations to which an aircraft travels the more revenue it earns and the more the running costs are spread over an aircraft design life. Deregulation per se allows for an aircraft to fly to several destinations allowing for airlines to compete favourably along certain routes, especially if the passenger demand allows it.

On the down side, Dolan (2003) notes that moving away from restrictive bilateral agreements towards liberalisation includes the fact that member countries can't choose to negotiate commitments to open specific service sectors to foreign competition and to afford foreign suppliers the same treatment as domestic suppliers. There is also a lack of ability to control the progressive liberalisation of access to and from their own markets, in a way that permits important national and regional concerns to be sensibly and responsibly considered. Finally, liberalisation also allows for trade-offs between all goods, services, forms of trading and almost all countries. In contrast, bilateral international aviation agreements are sector-specific and country-specific. Nearly all entitlements are negotiated between pairs of countries and the benefits accrued are restricted to those countries.

This implies that for a country to liberalise their bilateral agreements the process should be incurred slowly and carefully, like the US open skies Initiative which was the first bilateral liberalisation agreement ever made between the US and the UK.

### 2.3.3 Open Skies Initiative

From the positive effects of deregulation on the US domestic air industry, the US decided to liberalise their skies as they had done with domestic travel and expanded it to international air travel by creating bilateral agreements.. In 1992 the US began this initiative by agreeing to negotiate open skies bilateral agreements, which would involve bilateral agreements with the all European countries willing to permit US carriers' free access to their markets, on an individual country basis (Edwards, 2002).

The Department of Transport (DOT) in the US defined open skies as follows:

- Open entry on all routes
- Unrestricted capacity and frequency on all routes
- Unrestricted route and traffic rights including no restrictions as to intermediate and beyond points
- Pricing flexibility
- Liberal charter arrangements
- Liberal cargo regime
- Ability to convert earnings and remit in hard currency promptly and without restriction
- Open code-sharing opportunities
- Self-handling provisions (the right of a carrier to perform and control its airport functions in support of its operations)
- Pro-competitive provisions on commercial opportunities, user charges, fair competition and inter-modal rights

- Explicit commitment to non-discriminatory operation of and access to computer reservation systems

Wolf (2001) notes that when the US government had these open skies agreements with a number of its trading partners, the EU then set to establish multi lateral agreements between member states and from 1997 the inter-EU air transport was completely liberalised. Furthermore, the last decade has seen a trend towards multilateral intra-regional liberalisation in other parts of the world like South America, Africa, the Caribbean Community, South East Asia and the Middle East. The co-existence of different market regimes worldwide means that regulated routes may be bypassed by liberalised ones.

The effects of the open skies policy especially in the European Union was the cause for airlines performing better with more frequent flights and more city pairs being served and the airlines have a greater freedom of choice as to where and when they can deploy their aircraft. The passenger also has a better and greater choice of services at highly competitive prices (Morrison, 2004).

### 2.3.4 Airline alliances

An airline alliance is defined as an agreement between different airlines, to share routes, codes and slots as a way to break into different air transport markets. The airlines do not necessarily have to be originating from the same country or region in order to form an alliance. Oum et al. (2001) states that alliances between airlines serve to expand and strengthen globalisation. Alliances have provided a way for carriers to mitigate the limitations of bilateral agreements, ownership restrictions and licensing and control regulations. Hence alliances can be addressed as a measure of removing barriers between countries.

Wolf (2001), states that the last few years have seen the emergence of a growing number of strategic alliances between airlines from all around the globe, which coordinate several aspects of their operations including the building of integrated route networks that are operated by several partner airlines. From a cost point of view, mergers and to some extent alliances allow airlines to expand the size of the network with the following two main advantages (Nero, 1999):

1. Less duplication of capital investment, in particular the fixed/sunk costs associated with a new station.
2. Higher traffic density and therefore higher load factors in the different markets of the network, *ceteris paribus* (i.e. when flight frequency and aircraft type are constant).

Wolf (2001) comments that while such agreements between airlines may cover several aspects of the airlines' logistics and distribution, at the heart of many alliances lies the objective of coordinating schedules and fares as well as marketing efforts. What gives many alliances their strategic character is that they serve as a means to open new markets for the allied partners and to economise on operations which is done by:

- Circumventing legal restrictions on market access, as they allow carriers which do not hold the required traffic rights for their own operations or which do not possess slots at high density airports to benefit from the services provided by their partners
- Making marketing strategies more effective by raising the size of the integrated network the partners serve and by offering attractive through fares
- Lowering costs for the partners by generating favourable feeder relationships between airlines that increase capacity utilisation
- Injecting capital into airlines with which the alliance is being forged, in exchange for capital share within the airline company

To sum up, airline alliances may help to strengthen the competitiveness of carriers and route networks by increasing the threat of traffic diversion from regulated routes to liberalised ones. Alliances are prevalent among airlines for various reasons, but perhaps one of the most important is the negative reason that generally cross-border mergers and acquisitions between airlines are not possible. This is because most bilateral air services agreements between pairs of states (from which airlines derive the right to operate international air services) provide that a state may refuse to allow an airline from the other state to operate if it is not substantially owned and effectively controlled by that other state or its nationals. Hence a merger would entitle most of the other states to which such airline(s) operated to withdraw operating permission (Balfour, 2004).

The fundamental concern about alliances is how they affect the vitality of competition in the affected markets, which depends both upon the terms of the alliance and the carriers involved. This is a main concern for partners that have code sharing agreements, whereby an airline's designator code is shown on flights operated by its partner airline. The advantage of competitiveness could include creating new and improved services, lowering costs and increasing the efficiency of the airline for the passengers. The flip side is that they can result in market allocation, capacity limitations and higher fares or fore closure of rival companies because of route monopoly.

Within Africa, alliances have been taking place when national airlines which are usually dependent on their governments for subsidies, take on an alliance with a larger more established airline from overseas as a way of recovering from the high operating costs. The partner airline then has the advantage of buying its way into the African market very easily according to the conditions in the alliance agreement. Big alliances involve airlines from several continents and therefore operate on a global scale for example Kenya Airways originally from Kenya and the Royal Dutch airlines KLM from the Netherlands, allowing for either airline to tap into the markets shared in the different continents.

## 2.4 Yamoussoukro Decision

### 2.4.1 Background

The aviation industry in Africa in the late 70's and early 80's was characterised with problems some of which include mismanagement of national airlines, political interference, high operating costs and use of outdated equipment. Positive policies were needed to prevent the total collapse of most African national airlines especially those in the West African sub-region in view of the new developments in the world aviation industry, such as deregulation within the European Community and the USA, and privatisation of European airlines (Akpoghomeh, 1999).

Against this background, African ministers responsible for civil aviation met in Yamoussoukro, Ivory Coast in October 1988 to agree on how air transport should be used as an important instrument for social and economic development in Africa and to open up African skies. This heralded the historic Yamoussoukro Declaration of 1988, whose major objective involved unification of the African continent through liberalisation of the air transport industry. In July 2000, African ministers responsible for civil aviation, various Heads of State and the Government of the Organisation of African Unity (OAU) now known as the African Union (AU), adopted the Yamoussoukro Declaration whose name later changed to the Yamoussoukro Decision (YD) and it was made binding in law for all Member states of the AU. In accordance of Article 2 of the Decision, the YD takes precedence over all bilateral and multilateral agreements within the region which are not in conformity with it.

The general aim of the YD is to promote co-operation among African member states through their air transport policies. By deregulating the industry within Africa competition on routes will also encourage competition between airlines. Morrison (2004) adds that implementation of this decision will result in radical changes not only for airlines but national economies and result in increased tourism and greater availability and flexibility of air services.

The United Nations trade body responsible for regional integration within Africa called the Economic Commission for Africa (UNECA) report (2003), on the YD, stated that it was aimed at eliminating all physical barriers relating to,

1. The granting of traffic rights and particularly those falling under the fifth air liberty; enabling an airline from an African country to carry passengers between destinations in another state, which obviates the need for passengers travelling across the continent to pass in transit through points outside it.
2. The capacity of aircraft to be run by African airlines; To protect their airlines states had to hitherto impose restrictions on capacity in regard to carriers from other African countries, which was to the detriment of passengers because it imposed difficulties in finding places on the available regular flights.
3. Tariff regulation; traditionally tariffs were subject to lengthy approval procedures at the country level. Moreover, the tariffs were very high and the passenger did not have much choice in regard to tariffs.
4. The designation by states of operational arrangements; despite the increase in passenger traffic, the noticeable development of Africa's air transport industry and the sophistication achieved over the years, extremely protective policies persisted at the country level. These were in favour of the national carriers and could go as far as imposing restrictions against other airlines in regard to certain routes, even where there was no alternative air link. This situation led to daunting problems relating to the smooth flow of traffic within the continent.
5. Airfreight operations; there were situations whereby reason of restrictions on airfreight, agricultural commodities were spoilt through bio degradation, when no alternative means of transportation was available or the costs became too high.

### 2.4.2 Progress achieved

Even though the YD has not been fully implemented throughout Africa, the countries that have made progress towards achieving open skies have faced significant changes in the aviation industry elaborated below:

- A number of states have taken urgent measures towards implementation of the Decision, applying the agreements on the traffic rights on a bilateral basis. An example of this is the agreement between Ethiopia and several countries within Africa. Ethiopian Airlines flies to most of the major destination airports within Africa based on the bilateral agreements, which have been formed under the Decision
- Under the auspices of AFRAA, technical cooperation has made headway particularly with regard to plant pooling, joint fuel purchasing, retreading and purchasing of aircraft tyres (ECA, 2003).
- The African positions in relation to air transport regulations have been properly coordinated and defined at international forums as they are becoming increasingly aware of the stakes and implications of new air transport policies (ECA, 2003).
- The governments have scaled down their involvement in the management of airlines and airport authorities. Indeed, several initiatives have been taken to promote private sector participation in air

transport activities. As of 1996, at least 12 airlines have been proposed for privatisation and about 10 civil aviation authorities are to become autonomous (ECA, 1994).

- The measures adopted in Mauritius, with specific reference to the granting of fifth freedom rights has been implemented by many African countries, which has led to an increase in traffic and the frequency of flights on some routes (ECA, 1994).
- New routes are being flown through the flexibility that has been introduced with the granting of traffic rights (especially those of the fifth freedom) as agreed in Mauritius. Consequently, the intra-African network has improved somewhat. For example, the link between West Africa and southern Africa when South African Airways (SAA) in 2002 introduced a direct flight from Johannesburg to Dakar.
- Airlines that have not been able to adopt the liberalised environment are restructuring their services because of the competition and improvement in the quality of services.
- Alliances and co-operation arrangements have been established among African airlines in certain sub-regions for example: Air Mauritius, Air Madagascar and Air Seychelles, and SAA and Air Tanzania.
- The development partners have lent support to the process of liberalisation of air transport in Africa. The World Bank and the European Union are assisting the sub-regional economic communities to manage liberalisation and strengthen institutional capacities (ECA, 2003).
- In the 37th Annual General Meeting for AFRAA 2005, African ministers, airlines and government officials made a decision to speed up the YD implementation and a deadline of December 2006 was declared, as to the opening of all African skies.

### 2.4.3 Hindrances to implementation

Eighteen years after this famous Decision, which culminated in a new African air transport policy, the major objectives are still far from being realised, the implementation of it is moving at a slow pace in most African countries. Some of the reasons for the slow pace of progress include:

1. Lack of cooperation among some of the airlines and inconsistency of the National Policy Framework, which negates the spirit of the YD, thus causing delays in trying to incorporate the YD into national air transport policies at national and sub-regional levels.
2. Lack of effective coordination at national and sub-regional levels, poor participation from the private sector, misinterpretation of the Yamoussoukro accord and the Mauritius Decision on 5th Freedom rights (ECA, 1994).
3. The YD has become more about politics than about aviation, therefore it will require political intervention and leadership to be implemented. Furthermore, the countries that have implemented the Yamoussoukro with other like-minded states have done so on a bilateral basis, as opposed to the Open skies policy embedded in the YD (Morrison, 2004).
4. Since the early 1990s, African States have been experiencing political, economic and social turmoil. Their governments have not had the time they need to concentrate on developing the air transport sector, more specifically, airline cooperation and integration.
5. The airline directors are still distrustful of each other and hesitate to commit themselves to cooperation and integration arrangements. Furthermore, African airlines continue to individually operate air services to far destinations in Europe and Asia while there is an option with a lot of potential for cooperation and integration that has yet to be exploited. This can be done with the creation of African hub airports, which

will make it possible for individual airlines to consolidate traffic and thus operate daily flights to Europe and Asia from the hubs. What is more, the airlines fear that the implementation of the Decision might place them at a disadvantage in commercial terms (ECA, 2003).

6. Some countries and airlines continue to misinterpret the Decision or to interpret it to their advantage. Indeed for some of them, the objective of the Decision is to create regional groupings while for others the idea is more to create an enabling environment through wider liberalisation.

## 2.5 Institutional Frameworks Active in Implementing the Decision within Africa

There are many institutions within the African continent that are being used to implement YD. Others are regional organisations, which already have multilateral or bilateral air agreements with member states. Then finally, there are bodies that have been set in place regionally that have to regulate and standardise the aviation industry. A description of these organisations and the role they are playing to open Africa's skies are stated and institutions responsible shown in Figure 9.

### 2.5.1 Economic Commission for Africa (ECA)

The ECA is a United Nations Organisation specialised agency that is concerned with programmes in Africa like the fostering of development and the encouraging of sustainable trade policies through regional integration. ECA carries out policy analyses and programmes in areas such as aviation that will be instrumental in binding the continent, for example the ECA uses the consultants it recruited to conduct studies on:

1. The legal framework for integrating the YD in national policies
2. Air transport policy and the progress of integration in Africa through the implementation of the Decision
3. The model agreement between two or more countries for the establishment of a multinational airline
4. ECA also fielded sensitisation missions to impress upon certain countries the importance of the Decision objectives.

The ECA is directly involved in implementing the YD at regional and sub-regional levels and has the duty of entailing that the all-regional organisations involved in implementation are following the same procedures. It also serves the purpose of funding the workshops and seminars and technical assistance to clarify the articles of the Decision. It has also established a website http://www.uneca.org/itca/yammoussoukro which has details and updates on the implementation of the Decision.

### 2.5.2 International Civil Aviation Organisation (ICAO)

The major aim of ICAO is to regulate safety, communications and other technological aspects of the international aviation industry, with the vision "to promote co-operation between nations and peoples upon which the peace of the world depends". ICAO has regional and sub-regional offices within Africa that are supposed to ensure that in implementing the YD, all policies are according to the international standards and policies like the one on conflict resolution, which is not applicable for multi-lateral agreements, be rectified accordingly.

### 2.5.3 African Union (AU)

The Organisation of African Unity (OAU), now known as the African Union (AU), is a body that was set up with the aim of dealing with issues within the African region like conflict resolution, overseeing trade and regional policies with the ultimate aim of uniting the African continent.

The YD has been adopted by the AU in such a way that all member states of the AU are automatically supposed to implement the Decision. The date of implementation of the Decision was set at 12 August 2002 following its signing by the President of the 36th Ordinary Session of the AU Heads of State and Governments; thereafter the high-level organs of the AU, the Regional Economic Communities (RECs) and ECA should set in motion initiatives to ensure that States respect their commitments.

Accordingly, it is recommended that the future action of ECA, the RECs, the AU and agencies responsible for the development of air transport in Africa especially AFCAC should be focused on the implementation of the YD and organising meetings at the sub-regional and regional levels to provide the necessary technical assistance for capacity building and safety supervision

### 2.5.4 African Civil Aviation Council (AFCAC)

The African Civil Aviation Council (AFCAC) is a specialised agency of the AU that plays a key role in coordinating and negotiating with ICAO and other regions of the world in order to make sure that African views are taken into account in arriving at world decisions on air transport. At the international conferences on air transport, AFCAC's role is to defend the African Common Position on the future regulation of air transport in the YD.

AFCAC has set up a follow-up committee on the implementation of the YD. This Committee has been very actively sensitising member states and addressing the problems encountered. It has met several times to assess the progress made in the implementation of the Decision and reported thereon to the air transport committee of AFCAC (ECA 2003). It has also assisted the Economic Community of West African States (ECOWAS) to design a multilateral agreement on air transport. It participated in the sub-regional follow-up committee meeting held at Lomé, Togo which Côte d'Ivoire organised as coordinator.

### 2.5.5 African Airlines Association (AFRAA)

AFRAA is an association of all airlines operating within Africa that are owned by African member States with the objective among others, of harmoniously developing African air services. AFRAA has gathered information on the implementation of the Decision and informed members of its executive committee about the problems encountered and the progress made. It organises sub-regional meetings to which it had been invited by preparing and submitting documents such as the model text relating to the integration of the Decision in national air transport policies.

The African Airlines Association (AFRAA) has regularly kept its members informed on the status of implementation of the Decision and in collaboration with COMESA, organised a workshop for air transport companies. AFRAA has conducted studies on the effects of code sharing and franchising, within the context of liberalisation of air transport markets in Africa. AFRAA has also participated in meetings organised at the country and sub-regional levels by States and by RECs, on competition rules and the impact of the Decision.

### 2.5.6 Southern and Eastern Africa's regional trade organisations

The Southern African Transport and Telecommunications Commission (SATCC-TU) has regularly brought together directors of civil aviation authorities and airline managing directors to meetings where the implementation of the Decision, the legal mechanisms for strengthening the Decision, amending bilateral agreements and harmonising national laws has been discussed. SATCC-TU was also involved in setting up a follow-up committee for the YD implementation.

The Common Market for Eastern and Southern African states (COMESA) has been very instrumental in creating guidelines for member states on the implementation of the liberalisation policies in the air transport sector. It has also arranged for monitoring mechanisms through seminars and workshops for relevant aviation authorities, establishment of the COMESA council on air transport, which will harmonise policies and rules governing civil aviation.

The South African Development Community (SADC) in March 2002 organised a ministerial workshop in Mozambique, in which the Decision was strengthened by adopting it to the national laws of member states of the AU. This involved the formulation of articles in the Decision, devising an appropriate mechanism for settlement of disputes, establishment of a joint COMESA-SADC unit to monitor the implementation of the Decision and harmonising actions at the sub-regional level aiming towards uniform implementation in Africa.

Eastern Africa has the East African community (EAC), which hand in hand with COMESA and SADC has helped create awareness and has facilitated the formulation of the necessary regulatory instruments for implementation of the Decision. A ministerial workshop was held on 12 August 2002 by COMESA, EAC and SADC, involving the aviation industry stakeholders like civil aviation managers, air transport authorities and lawyers to enhance the understanding of the Decision and recommend the establishment of a joint monitoring body.

### 2.5.7 Central and West Africa's regional trade organisations

Formerly there existed the Banjul Accord Group comprising of The Gambia, Ghana, Sierra Leone, Cape Verde and Guinea whose major role was to accelerate the implementation of the YD. This was then taken over by the Economic Community for West African States (ECOWAS) which during its meeting held in Abuja from 22 to 25 July 1996, decided to create a single West African airspace. But until the September 14$^{th}$ 2007 meeting in Accra, ECOWAS was still urging civil aviation organisations and airlines to forge closer alliances. The main problem identified in their scenario is the lack of co-operation between Franco-phone and Anglophone States within the sub-region.

The Central African Economic and Monetary Community (CEMAC) and the Economic Community for West African States (ECOWAS) responsible for civil aviation signed a memorandum of understanding committing them to the implementation of the Decision in which they set out common guidelines involving (ECA, 2003):

1. Establishing the economic regulation for effective liberalisation
2. Strengthening safety and security
3. Sustaining the financing of air transport in West and central Africa.

Schlumberger (2004) states that these organisations have got further economic backing from the World Bank to arrange for follow-up meetings and seminars for the implementation of the Decision. From the funding they have received, CEMAC and ECOWAS organised:

- Workshops to develop an understanding of economic and technical regulation requirements in order to implement the YD successfully
- Studies on the consistency between West and Central African countries legal frameworks for civil aviation and the YD
- Studies for a new mechanism for the technical regulation of air transport services with a priority-training programme to develop the capacity of national civil aviation authorities in technical regulation.

### 2.5.8 North Africa's regional trade organisations

North African States through the Arab council on civil aviation has continued some of their liberalisation efforts and attained this by meeting some of the objectives set within the framework of the Arab Maghreb union (UMA). Meetings in which clarification of the concept of liberalisation, strengthening air transport cooperation and implementation of the liberalisation programme adopted by the transport ministers of the Arab League have been arranged (ECA, 2003).

## 2.6 Summary of Institutions

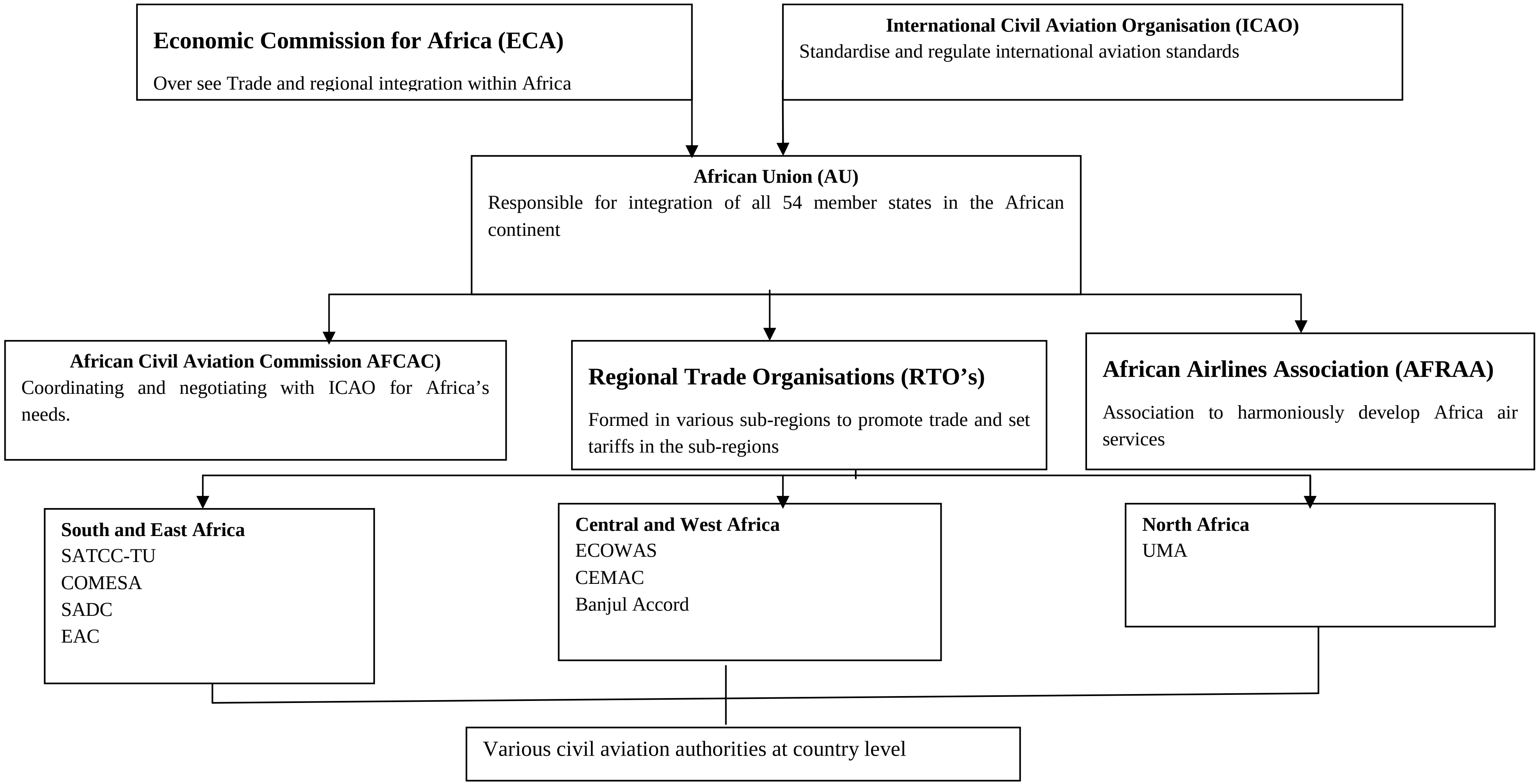



**Figure 9: Breakdown of Yamoussoukro implementation**

## 2.7 Monitoring Activities

The slow progress of the implementation of the Decision has been integrated into the activities of the AU by forming the regional follow-up organ, which comes under its presidency. The regional follow-up organ for implementation of the Decision was established in accordance with its article 9 and consists of the OAU/AU (President), ECA (Secretariat), AFCAC (Rapporteur), AFRAA and sub-regional organisations, which meet often to consider the questions raised by the various stakeholders and furnish the necessary solutions and clarifications toward facilitating the implementation of the Decision. The AU has also embarked on efforts to create awareness among member states on the implementation of the Decision by transmitting to States, under the signature of the Interim President, the documents on competition in air transport prepared by COMESA, SADC and the EAC. The AU participated in the drafting of the Memorandum of Clarification on the Articles of the YD (ECA, 2003).

The continental follow-up organ has adopted programmes and plans to support the implementation of the Decision. These programmes and plans cover, *inter alia*:

1. Capacity building: (sensitisation on the objectives and implications of the Decision)
2. Legal instruments and institutional dimensions and
3. Technical assistance to be provided to partners at their request.

At the request of the follow-up organ and some of the regional economic communities, ECA has, in collaboration with the regional follow-up organ, prepared a document on the legal clarification of questions raised at meetings organised to create awareness and broaden the reach of the Decision among countries. A Memorandum of Clarification prepared by the members of the regional follow-up organ on the basis of the document of clarification was sent to States under the signature of the Interim President of the AU.

## 2.8 Way Forward

The YD is among the formative instruments designed to streamline the development of Africa's airline sector. Its main objective concerns air transport cooperation, regional integration and progress towards attaining the objectives of the AU. Every effort should therefore be made toward its full implementation. The proposals given below are different measures that can be adopted in different countries in Africa to allow for Yamoussoukro or the benefits of liberalisation to happen at a faster pace.

### 2.8.1 Competition rules

It appears that fair play is not always observed particularly in regard to operational approaches, whereby some airlines have tended to unfairly eliminate other airlines in order to monopolise the market. Sub-regional organisations have therefore been requested to establish competition rules in a liberalised environment. COMESA, SADC and EAC have fulfilled that objective which may serve as a beacon for other sub-regional organisations.

The necessary steps are being taken at the sub-regional level to formulate competition rules – which may result in sub-regional blocs – the follow-up committee is urged to formulate a harmonised set of rules governing competition at the regional level. States should use ICAO instruments and the relevant provisions of the multilateral agreement on air transport adopted by Asian States.

### 2.8.2 Alliances

Balfour (2004) points out that like in the case of the KLM/Northwest alliance, where Netherlands and the US signed an open-skies agreement in September 1992, and international airline alliances could be proposed with the following conditions:

1. Each air carrier's management remains separate due to national ownership restrictions by each government, but coordinates closely.
2. High level of integration can be done without the fear of legal challenges from competitors.
3. Marketing strategies can be discussed and pricing, developing formulas to set fares in all markets and change fares quickly in response to changing market conditions.

The reason for these rules was that in exchange for signing an "open skies" agreement the US would grant anti-trust immunity to airlines from the US and its bilateral partner country enabling them to coordinate capacity and fares.

In Africa, this occurred when national airline Kenya Airways formed an alliance with the Royal Dutch airlines (KLM). The Kenyan government still with majority shares in Kenya Airways, benefited from the capital injected with the alliance and was even able to expand to more destinations within the African continent and beyond. This measure should also be taken by smaller national airlines forging an alliance with larger African national airlines.

### 2.8.3 Business regulations

Most of the operators are not acquainted with the procedure to follow in regard to operational licenses where air transport services have been liberalised. Some have proceeded to apply the provisions of the YD on agreements negotiated bilaterally. Such actions have spawned confusion and operational difficulties for some air transport services. To address this situation, it will be recommended to sub-regional organisations and the follow-up committee to prepare a manual on the regulation of licensing procedures for air transport operations in Africa (ECA, 2003).

### 2.8.4 Unilateral liberalisation

In cases where countries with smaller national airlines are scared of being swallowed up by the competition on routes presented by the YD, they can open up their skies cautiously in the system on unilateral liberalisation.

Wolf (2001) proposed unilateral liberalisation, which would involve a single country opening its own markets without demanding anything in exchange. What the country would have to be sceptical about is route monopoly of a larger airline dominating all the major routes. This implies that instead of waiting for Yamoussoukro to be implemented regionally, steps towards opening countries individual skies would be a stepping stone for other countries to follow suit. The logic would be to encourage healthy competition on international markets for the benefit of the national economy.

### 2.8.5 Low cost airlines strategy

The aviation industry lately been bombarded with low cost airlines, which are performing extremely well in terms of profitability. Morrison (2004) writes that African airlines have been depending on their governments for subsidies for many years, because of the highly capital intensive and low profit margin characteristics of the air transport industry. One of the ways out of lowering running costs is adopting the low cost airline operating strategies, some of which include use of e-tickets, cutting down the frills of the service like food and flight crew and flying smaller aircraft which are less expensive to run. These low cost airlines would specialise mainly on the short-haul market, with flight durations typically between 1-2 hours.

### 2.8.6 Government involvement

Morrison (2004) suggested that one of the drawbacks of the YD is the fact that its implementation regionally has now become a political decision, because the airline industry ownership within Africa was historically state-owned. The changes necessary would involve that the regulator of the industry needs to be better defined, independent and decision making policies impartial. The regulator should operate within a predefined policy framework preferably in line with the YD thus making the policy maker and regulator of separate identity. Some countries in Africa have gone further and privatised their airlines completely while some have remained majority share holders in commercialised state-owned airlines, a step in the right direction to reduce government involvement.

### 2.8.7 Unification of airlines

Even though almost every country has its own national airline or flag carrier, this idea can not work in Africa's open skies or else we shall have 60 official airlines operating on one route. What happens then to airlines that have less modern aircraft? We also forget that the passenger demand in Africa is not that high enough to warrant such competition and still keep all those airlines running profitably. Morrison (2004) suggests that Africa reduce aviation fragmentation and aim to have only four or five strong regional airlines, which would enjoy the economies of scale to survive the competition.

These sub-regional airlines would be chosen based on the sub-regional trade organisations in Africa in implementing the open skies. This would allow for the creation of hubs within these geographical regions, which would mean that a hub network could work within the African continent and the smaller airlines feed passengers from the nodes into these hubs. This would be the best solution as the regional trade organisations have been the most instrumental in trying to implement the YD, which would liberalise Africa's skies.

# CHAPTER 3: HUBBING THEORY

## 3.1 Introduction

Button et al. (2002) state that in order to minimise costs and keep airfares down, airlines need to keep aircraft in the air for the longest possible time to achieve the highest possible load factor, and to coordinate their aircraft, crew and maintenance schedules. To achieve this, many airlines operate hub-and-spoke (H&S) networks which entail consolidating traffic from a diverse range of origins, destined for a diverse range of final destinations at hub airports. In the airline industry, one of the most striking changes precipitated by deregulation in the US has been the restructuring of carrier networks from a mostly linear to an H&S structure, because of the major cost reduction incurred in these networks (Levine,1987).

This chapter deals with hubbing as a cost-minimising option for airlines and route networks. Literature relevant to the effects of hubbing and cost-effective methods of carrying out hub network design is investigated, and finally, the methodology for designing an H&S network applicable to the Africa air network is developed.

## 3.2 Hub Classification

Hubs are defined as collection points that serve the purpose of consolidating traffic flow. The concentration or consolidation of flow can reduce movement costs (i.e. transportation or transmission) through economies of scale, even though the distance travelled may increase (Campbell, 1996). Hubs are usually found with air networks, mail delivery systems and in telecommunications.

Hubs can be defined in two general ways: one denoting whether an airport represents a hub within a carrier-independent system of air transport (i.e. airport level) and the other denoting its role within a carrier-specific network (i.e. airline level). In the analysis of hubbing, the definition of what constitutes a hub becomes crucial (Schnell and Huschelrath, 2004). For example, O R Tambo International Airport in South Africa is a hub at airport level for a number of movements within Africa and in between continents, i.e. Australia and America, while it also acts as a hub at airline level for South African Airways, the national flag carrier for South Africa. Empirical studies differ in the criteria used to define what constitutes a hub (Button et al., 2002). Table 2 shows that hubs have various definitions, depending on the function they perform, and also shows some of the classification of hubs in their specific categories.

For the purposes of this study, a hub will be defined by its route structure, i.e. its function as a distribution point for air travel to and from its surrounding catchment area, with connecting services, irrespective of the number of originating passengers.

**Table 2: Various functional definitions of airline hubs**

| **Functional definition** | **Explanation** | **Examples** |
|---|---|---|
| *Scope* | | |
| Operational | Merely an operational base<br>No connecting services offered | London-Stansted (Ryan Air, Easy Jet)<br>Frankfurt-Hahn (Ryan Air) |
| Marketing | Operational base<br>Connecting services | London-Heathrow (British Airways)<br>Frankfurt, Munich (Lufthansa) |
| *Route structure* | | |
| Hinterland | Hub serves as a distribution point for air travel to and from its surrounding catchment area | Chicago (American Airlines)<br>Dallas (American Airlines) |
| Hourglass | Interface between short- and long-haul flights<br>Directionalised routing (e.g. north-south, east-west) | Vienna (Austrian Airlines)<br>Helsinki (Finn Air)<br>Madrid (Iberia) |
| *Strength of local market* | | |
| Weak | Relatively few originating passengers | Amsterdam (KLM)<br>Reykjavik (Iceland Air) |
| Strong | Relatively many originating passengers | London-Heathrow (British Airways) |
| **Category** | **Explanation** | **Examples** |
| *Size* | | |
| Primary | Most important airport of an airline<br>Focus on intercontinental traffic (if applicable) | London-Heathrow (British Airways)<br>Frankfurt (Lufthansa)<br>Munich (Lufthansa) |
| Secondary | Second most important airport of an airline<br>Focus on intercontinental traffic (if applicable) | |

Source: Schnell and Huschelrath (2004)

## 3.3 Advantages of Hubbing

### 3.3.1 Economies of traffic density

Economies of scale (which in transport refer to traffic density) occur when the average unit cost of production declines as the amount of traffic increases between any given set of points served (Barla and Constantos, 2000). The usual argument is that an H&S network, through increased traffic density on the links to the hub (the spokes), allows airlines to use larger, more efficient aircraft and to spread the fixed costs over more passengers, thus exploiting economies of scale. Besides empirical evidence of improved returns from traffic density, other empirical studies underscore the cost advantage of hubbing. McShan and Windle (1989) suggest that a 10% increase in hubbing is associated with a 1.1% decline in unit cost, all other costs remaining equal. The technical distinction between economies of scale and scope can be seen by reference to Equation 1 where C denotes cost and Q is output; economies of scope are assessed as follows (Button et al., 2002):

$$\mathbf{S = \{[\,C\,(Q^1) + C\,(Q^2)] - C\,(Q^1 + Q^2)\} / \{C\,(Q^1 + Q^2)\}} \qquad \textbf{Equation 1}$$

Where:

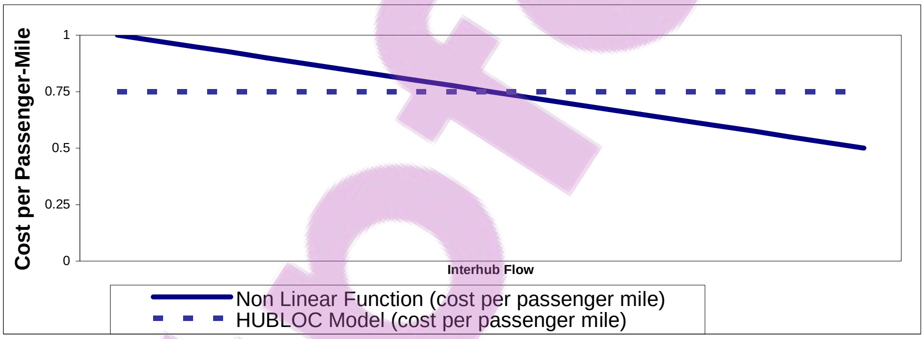
| | | |
|---|---|---|
| $C\,(Q^1)$ | = | the cost of producing $Q^1$ units of output one alone |
| $C\,(Q^2)$ | = | the cost of producing $Q^2$ units of output two alone |
| $C\,(Q^1 + Q^2)$ | = | the cost of producing $Q^1$ plus $Q^2$ |

Economies of scope exist if S > 0, while economies of scale exist if S falls as Q expands.

Furthermore, airlines introduce cost savings on indirect routes, which lead to profit-maximising prices that are well below those of direct routings, such that the lower price may over-compensate for the disutility of longer travel times and the inconvenience of changing planes (Wojahn, 2001).

The generalised cost, which is defined as the overall cost of making a trip, including all 'time costs', will also involve a number of non-transportation costs that are influenced by the quality of transportation provided. For example, more frequent air services from an airport reduce the likelihood that a traveller will have to bear the financial and time costs of an overnight stay on routes with low service frequencies. High frequency of services also means there is less 'down time' wasted as participants in international business meetings wait for fellow attendees from less busy routes to arrive (Button et al., 2002).

O'Kelly et al. (1996), in analysing the effect of an increase in discounts on hub links as passenger flow varies, found that for an H&S network, costs increase at a decreasing rate as passenger flow increases. As shown in Figure 10, with the non-linear function effect in their model, agglomeration of flow provides a benefit in that the rate at which the per-mile travel costs increase, decreases as flow increases, unlike the conventional hub location model (HUBLOC) which implies that as the flow on hub links increases, the discount stays constant.




Source: O'Kelly et al., 1996

**Figure 10: Costs per passenger-mile non-linear cost function and HUBLOC model**

From the above literature studies, it appears that through the lower costs of travel realised by increased flow on hub links, the benefits of traffic density in an H&S network are achieved through economies of scale (S) derived when output (Q) increases.

### 3.3.2 Quality of service

Hubbing offers higher flight frequencies and thus better-quality service and consumer value, necessary qualities used to measure prolonged customer satisfaction and on-going propensity to utilise products and services (Schnell and Huschelrath, 2004). The existence of the economies of scale (market) provides the consumer with a larger set of services to choose from (non-stop or with a connection), generated by greater traffic flow for the carriers (Button et al., 2002).

Button et al. (2002) found that even though the 1978 US Airline Deregulation Act contained provisions for financial support services to smaller communities (the Essential Air Services Program), the hub-and-spoke operations that came about as a result of deregulation actually stimulated the provision of services to smaller communities. Funnelling traffic through hubs makes it viable to offer higher-quality services to many smaller communities.

### 3.3.3 High average yield

Hubbing allows airlines to have a high average yield due to a wider 'market power', which is the ability of a market participant to control sufficient/essential facilities, to set prices profitably above, or reduce supply below, those which would occur in a fully competitive market (Schnell and Huschelrath , 2004). It was also found that hubbing was a preferred option once an airline's size and network structure had grown to a certain scale. The fact that aircraft are full or close to full with a blend of passengers with various elasticities of demand means that the airline can engage in very sophisticated demand-management and pricing schemes, effectively micro-managing the yield from the contents of the flight, based on the passengers' ability and willingness to pay (O'Kelly et al., 1996).

### 3.3.4 Better capacity allocation

Barla and Constantos (2000) show that hubbing has the added advantage of better allocation of capacity under demand uncertainty. Hubbing by pooling passengers from several markets into the same plane allows the firm to adjust the allocation of capacity once the demand conditions are revealed. This flexibility means that if the demand in one market turns out to be low, thereby creating excess capacity, the firm can increase sales in other markets. Moreover, if the demand in one market ends up being high with consequent binding capacity constraints, especially during peak seasons, hubbing allows a more profitable allocation of capacity since the firm can first price out the low-value travellers on several markets before eliminating travellers with higher willingness to pay.

### 3.3.5 Marketing advantages

Hub networks for airlines need little effort in marketing because airlines are readily associated with flights to and from the countries whose names they carry, such as British Airways, Air France, Alitalia, Austrian Airlines and Japan Airlines. It needs little marketing effort and few out-of-pocket expenses to inform a potential customer residing in California about the direct airline services of British Airways for a flight to London, Heathrow.

Besides increased production efficiency, Nero (1999) adds that an airline with a large presence in a hub airport gains significant customer loyalty advantages through marketing devices such as frequent flyer programmes and travel agency commission overrides. The existence of such marketing devices, combined with the fact that travellers value H&S network characteristics (higher frequencies of service, more connection points and a wider variety/selection of destinations), allows an H&S airline to exercise some monopoly power at the hub airport.

### 3.3.6 Stimulation of job creation

Hubs stimulate job creation, especially in the US high-technology sector. Statistical calculations done for 56 hub airports in the US indicated that having a hub airport in a region improves the economy through the employment of more than 12 000 personnel. This does not mean that all hub regions benefit by this amount, but it was an average calculated across hub cities. What these econometric calculations show is that any increase in air passenger traffic at hub airports has a positive effect on employment in the surrounding metropolitan areas (Button et al., 1999). This is because traffic at hub airports in general is higher than traffic at other airports; it can therefore be inferred that hub airport cities accrue greater economic benefits than non-hub airport cities. Peeters et al. (2001) also indicate that H&S networks have a higher impact on the global environment than point-to-point networks, and that a hub airport has a higher impact on the local environment in terms of infrastructure development.

## 3.4 Disadvantages of Hubbing

The disadvantages of hubbing that have been identified in the literature are given below.

### 3.4.1 Additional running costs

A direct and non-stop flight is difficult to beat economically. The additional cost of landing and handling at an intermediate point is avoided and, more importantly, it does not add to unproductive ground time of the aircraft and crew. On product appeal, the seasoned traveller prefers the most direct itinerary, non-stop if possible, without a change of aircraft and flight at an intermediate station. H&S operations increase route frequencies, which in turn negatively affects airline costs (extra fuel consumption, extra cruise time, extra fixed costs associated with take-off/landing operations, etc.). Most fares, especially the long-haul fares, reflect the reduced route cost of the wide-body jets and their extended operating range, often allowing non-stop operation. It is therefore reasonable to assume that there is little or no margin left for a fare to cover the extra cost of the additional travel sector, especially when the through fare undersells the local fare (Zollinger, 1995).

Zollinger (1995) also points out that in order to secure a market share of traffic beyond one’s national gateway, which is usually the case with H&S networks outside their countries’ boundaries, like in the European Union, one needs to use costly and disproportionate efforts in advertising, promotion and solicitation activities, such as canvassing and servicing the necessary distribution channels, leading to varying operating costs and thus increasing the marginal cost price.

### 3.4.2 Additional travel time

Button et al. (2002) show that the need to go via a hub imposes additional costs on a traveller in terms of actual travel because of the added segment lengths involved and the transit time spent at the hub. In a hub network, direct flights do not exist, except if a passenger’s final destination is the hub at which the aircraft first lands. This means that hubbing inconveniences passengers by adding extra travel time through the hubs and the transit time at hub airports before passengers reach their final destination. As shown in Figure 11, a passenger originating from A has to go through three extra sectors – A-B, B-C and C-D – before reaching destination D, whereas a direct flight – A-D – would shorten the journey.

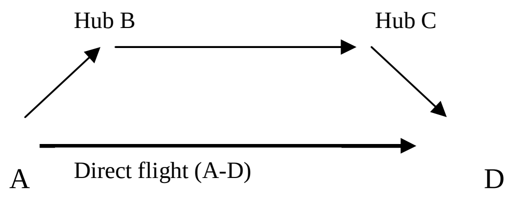



**Figure 11: Travel time added by hubbing**

### 3.4.3 Unfair monopoly on routes

Hubbing tends to discourage entrants into a hub market, especially for a route where the rival has a hub at one endpoint and hub-to-hub routes. In the US especially, new entrants usually leave the market after a fare war when the route in question offers service to another carriers' hub (Schnell and Huschelrath , 2004). Button et al. (2002) disagree with this point, stating that some smaller carriers that entered the US airline market managed to find a niche for themselves by offering a particular kind of service, such as low-cost carriers, or by avoiding direct competition with a major carrier or, conversely, by tying in with a major carrier (notably a regional carrier).

Due to the fact that an airline operating within a hub network has a frequency advantage on a route, it enjoys a fare advantage. For example, Air France, Lufthansa and Swiss and most airlines in the US are found to charge a hub premium, making average fares higher (if at least one end-point is a hub) by an average of 4%.

### 3.4.4 Congestion at hub airports

For airlines there is a restriction to expansion at congested hub airports due to lack of slots in which planes can land. As a result, there is reduced flexibility on scheduling, which increases susceptibility to delays in emergency situations (Schnell and Huschelrath , 2004). Conversely, Button et al. (2002) argue that larger hub-based carriers enjoy economies of market presence and can offer more efficient network services because of scope, scale and density advantages and therefore have a greater incentive to press for additional infrastructure for runways, gates and slots at the hub airports.

Airlines that provide connecting services that flow through hub airports schedule their flights to arrive and depart in 'banks', which are periods of time in which many planes arrive and depart over a short time-span to facilitate connections. This inevitably means that there are considerable numbers of both passengers and aircraft congregated at the hub during each of these banks (Button et al., 2002). Such congestion does pose problems for fliers, who find themselves at a crowded facility, and for the airlines, which have to get their planes turned around to meet schedules. At hub airports where one carrier has a very significant amount of the traffic, the congestion costs are borne largely by its own operations and by its own passengers. In economic terms, the airline internalises the congestion costs of its interactive activities and passes them on to the passengers as levies within their fares – to the detriment of the passengers.

### 3.4.5 Limiting of competition

Hub carriers limit competition through the excessive market power enjoyed at their hubs because they are free from competitive pressures. Button et al. (2002) argue that the interest, which is the real test of competitiveness, is the degree of choice available to customers between their origin and desired destination. Increased levels of competition arose after the 1978 deregulation in the US market when there were an unsustainable number of new market entries at the route level as new airlines and incumbents experimented with services in the new open-market environment. Furthermore, hub carriers do face competition from specialised airlines, such as low-cost carriers (LCCs), and from technology changes, such as the preferred use of regional jets and new aircraft like the 'extended range' aircraft that fly over longer distances without the need to refuel. All these factors encourage competition on routes in hub networks.

Zollinger (1995) concludes that hubbing cannot be relied on to provide a lasting solution. It falls short of the main objectives for an airline's long-term success, which include economy of operation and product appeal. Airline planners would be well advised to look for ways to adjust the capacity offered to the genuine demand for scheduled air travel. A solution is at hand, however, since now smaller aircraft are on offer for operating short- or long-haul flights without sacrificing comfort for economics.

### 3.4.6 Environmental costs implication of hub networks

Research work has been done to calculate the noise and emissions in the air transport industry. The effect of H&S networks on the environment has been an area of growing concern. This is because H&S networks are characterised by longer travel distances through hubs and higher frequencies.

The social cost impact of the noise and emissions from the routes and networks in which hubs were bypassed was found to be significantly lower than that of the H&S networks. The differences in the environmental costs per passenger (noise and emission costs) ranged from 25% to 71%. This was found to be dependent on the concentration of population around the airports and the degree to which the hub routing involves extra mileage (Morrell and Lu, 2007)

## 3.5 Airline Hub Network

Campbell (1996) defines a hub network as one that includes nodes to represent the origin, destination and hub locations, and arcs to carry the flow. Such a network provides connections between the origins and destinations by routing flow via hub facilities. This reduces the number of arcs required to connect all origins and destinations, and it concentrates flow on these links. The creation of hubs in an air network entails designating specific airports as hubs and all the other airports as nodes in the network. The most important factors in transportation hub networks include the flow cost of transportation, i.e. moving the freight or people between origins and destinations, and the paths that the passengers will have to travel on these routes.

### 3.5.1 Effectiveness of hub networks

Hubs in the US succeed mostly between secondary points where no direct flights are easily available because a customer can then accept a routing through a hub and the airline can attempt to charge the full cost of each sector flight (Zollinger, 1995).

Evidence was found in the US implying that the network concentration leads to lower costs only if the carrier in question operates a large network. A survey analysis was then carried out in which a questionnaire was developed to determine airline managers' assessment of the effectiveness of H&S networks in other areas (Schnell and Huschelrath , 2004). This survey covered airlines having their home base in one of the four liberalised markets, that is Australia/New Zealand, Canada, the EU[1] or the USA. The results of the analysis and possible reasons given for the effectiveness or otherwise of H&S networks are summarised in Table 3.

**Table 3: Number of hub airports categorised by size of hubs, region[2]**

| Region | Greatest number of hub airports in 2002 | Destinations served within the region | Gini coefficient measuring average connectivity | Possible reason |
|---|---|---|---|---|
| USA | 19<br>7<br>5<br>4<br>16 | 20-29<br>30-39<br>40-49<br>60-69<br>>=70 | 0.5854 | Liberalisation occurred earlier, so airlines and hub airports have been well established since deregulation in 1978. |
| EU | 19<br>13<br>6<br>4 | 20-29<br>30-39<br>40-49<br>50-59 | 0.5557 | Hubbing imposes additional travel time on passengers and this competes with the efficient road and rail network within the region. |
| Canada | 2 | 20-29 | 0.4000 | The geographical location of hub airports and competing alternative modes of transport are disadvantages. |
| AUS/NZ | 2<br>1 | 20-29<br>30-39 | 0.4360 | The geographical location of the cities served offers few benefits. |

Source: Schnell and Huschelrath (2004)

The results given in Table 3 show that the difference in the number of hub airports is due to the difference in size of the regional market. However, the Gini coefficient, which is a defined as a measure of statistical dispersion, is used to measure the effectiveness of hub airports in serving the various destinations for each of the regions. The hub networks of US airlines and EU airlines were calculated to have the highest coefficients since their airlines serve more routes from relatively few hub airports. This implies that there are more routes with a hub at one of their end points in the EU or the USA than in the other two regions, namely Canada and AUS/NZ (Schnell and Huschelrath, 2004). This suggests that there is a legitimate question regarding the potential efficacy of H&S systems in Africa – a question that this study will try to address.

### 3.5.2 Hub location

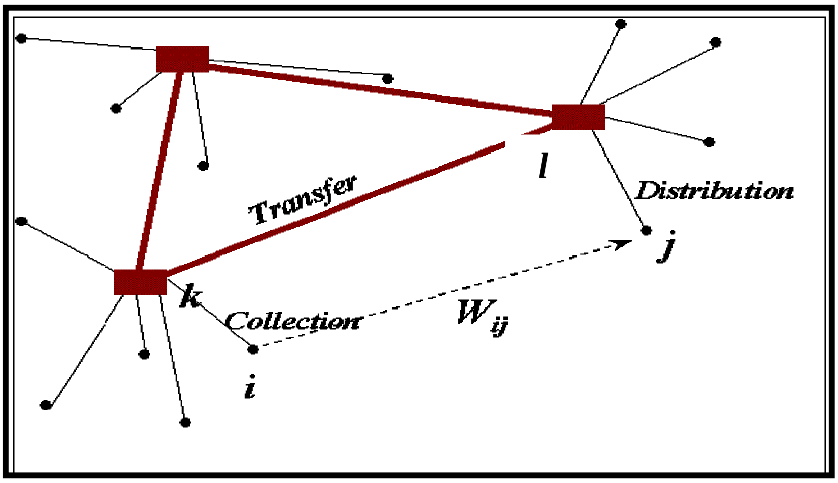
Boland et al (2004) define the hub-location problem as one concerned with creating hub-and-spoke networks, which involves locating hubs and assigning non-hub nodes to hubs with the objective of minimising transportation costs across the network. The basic information available in hub-location problems is a set of n nodes that need to exchange a known amount of flow, $W_{ij}$ (passengers), between each pair of nodes, *i* and *j*.

[1] Including Norway and Iceland, which are both a part of the European economic area to which liberalisation of European air transport applies.

[2] Schnell's own calculations are based on OAG data, where the number of destinations refers to airports served by the hub operator itself or on behalf of the hub operator. This calculation is based on an operational view of hubs (Schnell, 2004).

While the simplest method of achieving this would be to connect each pair of nodes directly, this is too inefficient in a hub network and therefore all communication occurs by routing the flow via a set of hubs. The location of the hubs must be chosen from among the original set of nodes which act as collection, consolidation, transfer and distribution points, such that transferring flow between hubs is cheaper than the cost of moving flow to and from non-hub nodes.

It is usually assumed that the hubs are fully interconnected and any non-hub node can be connected directly to a hub. Note that in some cases this may require pre-processing by calculating the shortest paths through an underlying transportation network. With these assumptions and restrictions, all flow must then be routed via one, or at most two, hubs. In general, we write that flow from *i* to *j* goes via hubs *k* and *l*, where *k* and *l* could be identical if the flow is via only one hub and similarly $i = k$ if i is itself a hub or $i = j$ if *j* is a hub. The transportation cost as shown in Figure 12 for this connection consists of a collection cost from *i* to *k*, transfers costs from *k* to *l* and distribution costs from *l* to *j*. Some of these costs may be zero if two of these nodes are identical. Furthermore, in most applications the cost would depend on the geographical distance between the nodes in some way.




Source: CMISRO (2003)

**Figure 12: Hub network flow**

### 3.5.3 Capacities

The CMISRO (2003) defines airport capacity as the limit on the amount of flow being collected by non-hub nodes from hub nodes. Capacity is important at hub airports because of the congestion that can arise at such airports due to the limitations in facilities (in terms of gates, runways and hangars) that are realised when an airport becomes a hub. Airport capacity is of concern when there is need to consider an alternative route or a direct flight between i and j if this will cause the capacity of the hub airport to be exceeded when flow is consolidated.

### 3.5.4 Flow thresholds

The CMISRO (2003) defines flow thresholds as the minimum flow that is needed on some or all of the links. The flow thresholds for each of these hubs could be taken into consideration, so that the flow carried would correspond to the smallest plane operated by the company.

## 3.6 ρ-Hub Median Problem

The ρ-hub median problem is explained as the situation, when designing a network, where a fixed number of nodes (ρ) are allocated to be hubs and the remaining nodes have to be allocated to one or more of the chosen hubs in such a way that the operating costs of the resulting network are minimised. There are many methodologies through which the ρ-hub median problem can be solved and the study will look at the most common methodologies that have been used.

### 3.6.1 Single Allocation ρ-Hub Median Problem (USAρHMP)

The most widely studied variant is known as the Uncapacitated Single Allocation p-hub Median Problem (USAρHMP). In this variant exactly ρ hubs must be allocated among the *n* nodes and each node is allocated to only one hub (CMISRO, 2003). Analytical research on the hub-location problem began when O'Kelly (1987) devised a mathematical formulation of the problem defined as follows: Given *n* interacting nodes in a network, the flow between pairs of nodes *i* and *j* is denoted by $W_{ij}$ ($W_{ii}$ = 0 by assumption), while the transportation cost is denoted by $C_{ij}$ (unit of flow between nodes *i* and *j*, with $C_{ii}$ = 0) and ρ is the number of hub facilities to be located ($\rho<n$). The hub-hub discount α, on the costs of flow $C_{km}$, for the hub-hub link is assumed to apply to all hub-hub links in the network regardless of the differences in the flow travelling across them. The problem involves finding the location of the hub facilities and thereafter assigning the nodes that minimise the total transportation cost. The first integer program formulation was proposed by O'Kelly (1987) for USApHMP, using a quadratic objective function. This problem is formulated as given below:

**Minimise** $$Z = \sum_i\sum_j\sum_k\sum_m W_{ij} [X_{ik}\, X_{jm}\, (C_{ik} + \alpha\, C_{km} + C_{jm})] \qquad \textbf{Equation 2}$$

Subject to

$$\sum X_{ik} \leq (n-p+1)\, X_{kk} \qquad \text{for all } k, \qquad \textbf{Equation 3}$$

$$\sum X_{ik} = 1 \qquad \text{for all } i, \qquad \textbf{Equation 4}$$

$$\sum X_{kk} = p, \qquad \textbf{Equation 5}$$

$$0 \leq X_{ik} \leq 1 \text{ and integer for all } i \text{ and } k$$

Where:

| | | |
|---|---|---|
| n | = | the number of nodes in a network |
| ρ | = | the number of hubs to be located |
| α | = | the hub-hub discount 0< α < 1 |
| $W_{ij}$ | = | the amount of flow travelling between *i* and *j* |
| $C_{ik}$ | = | the per-unit cost of travelling between *i* and *k* |
| $X_{ik}$ | = | 1 if node *i* is allocated to hub *k*, 0 otherwise |

The object function in Equation 2 minimises the total network cost. The constraint in Equation 3 requires a hub to be open before a node is assigned to it. Equation 4 constrains each node to be assigned to a single hub. The constraint in Equation 5 requires that ρ hubs be open. The quadratic solution is the easiest to understand even though it is not useful for obtaining solutions directly, especially for larger networks which are more complex.

#### 3.6.1.1 Heuristic algorithms

Due to the quadratic nature of the hub-location problem, heuristics were then used in the hub-location and allocation methodology for larger, more complex networks, with more than 25 nodes but fewer than 95 nodes in a network, to derive a single solution (Bryan and O'Kelly, 1999). Heuristics describe a set of rules developed to attempt to solve problems when a specific algorithm cannot be designed.

A variety of heuristic algorithms have been derived and researched for various hub-location problems and this research has been outlined by Bryan and O'Kelly (1999) as follows:

- O'Kelly (1987) developed the first two heuristics that computed upper bounds with the optimal objective function value for the single-assignment model.
- Aykin (1990) used flow-based assignment rather than the nearest-hub approach used by O'Kelly (1987).
- Research was then carried out to tighten the upper bounds and bring us closer to the true optimal solution: Campbell (1996) used specialised heuristics; Abdinnour-Helm et al. (1992, 1993), Aykin (1995), Ernst and Krishnamoorthy (1996, 1998) and Smith et al. (1996) used heuristics borrowed from physical sciences such as simulated annealing.
- Similarly, lower bounds for tightening the USAρHMP were researched by O'Kelly (1992) and O'Kelly et al. (1995), and a numerical comparison of many of these all these heuristics was done by O'Kelly et al. (1996).

#### 3.6.1.2 Tabu Search

Tabu Search (TS) is an iterative search procedure that moves from one feasible solution to another; it is used mainly to allocate appropriate hubs to a network. Klincewicz (1991, 1992) used clustering/greedy exchanges and TS to allocate nodes to hubs. In this procedure, after a move has been made it is classified as forbidden ("Tabu") for a certain number of iterations in the future. The primary purpose of assigning a Tabu status is to prevent cycling and to pick the optimal solutions by localising the search.

#### 3.6.1.3 Genetic Algorithms

Genetic Algorithms (GAS) is a search algorithm used for finding the near-optimal solutions in large spaces. It was inspired by population genetics, using the mechanics of natural selection and natural genetics. The GAS method has been adopted for many operational research problems such as scheduling problems and the "travelling salesman" problem, and has been applied to location-allocation problems like the USAρHMP by Topcuoglu et al. (2005).

#### 3.6.1.4 Hybrid heuristics

This form of heuristic was used by Abdinnour-Helm (1998), who applied a hybrid of Genetic Algorithms (GAS) and Tabu Search (TS) to create a model formulation called GATS. In this method a combination of the strength of GAS is used to solve the first level of the UHP-S (selecting the number and the location of the hubs), by diversifying the search, and the strength of TS is applied to solve the second level (assigning the spokes to the hubs), by narrowing down the search in a model for USAρHMP.

#### 3.6.1.5 Linear programming

Bryan and O'Kelly (1999) use linear programming in hub-location research, employing the linearised version of the quadratic Equation 2 to locate and allocate hubs. Campbell (1994b) allows the use of linear programming to provide integer solutions even though it is restricted to small networks. A little later Skorin-Kapov et al. (1996) achieved a tight linearised version of the same hub-location problem, without forcing integrality, through the use of integer programming, such that exact solution values of costs were obtained for small-sized problems of up to 25 nodes.

### 3.6.2 Multiple Allocation ρ-Hub Median Problem (UMAρHMP)

In the Multiple-Allocation Hub-Location Model (UMAρHMP) originally formulated by Campbell (1994b), each interacting pair is allowed to utilise the hub that will result in the lowest travel costs for a particular origin to destination path. This implies that any single non-hub node may be allowed to interact with more than one hub if in doing so it results in lower total network costs. The UMAρHMP problem is well explained by the tight linearised version of the UMAρHMP model shown below, which was derived by Skorin-Kapov et al. (1996) and is referred to as HUBLOC. The objective function derived minimises the total network cost.

$$\mathbf{MIN}\ \Sigma_i \Sigma_j \Sigma_k \Sigma_m W_{ij} (C_{ik} + \alpha C_{km} + C_{mj}) X_{ijkm} \qquad \textbf{Equation 6}$$

Subject to

$$\Sigma_k Z_k = \rho \qquad \textbf{Equation 7}$$

$$\Sigma_k \Sigma_m X_{ijkm} = 1 \quad \text{for all } i \text{ and } j \qquad \textbf{Equation 8}$$

$$\Sigma_m X_{ijkm} - Z_k \leq 0 \quad \text{for all } i, j \text{ and } k \qquad \textbf{Equation 9}$$

$$\Sigma_k X_{ijkm} - Z_m \leq 0 \quad \text{for all } i, j \text{ and } m \qquad \textbf{Equation 10}$$

Where:

| | | |
|---|---|---|
| a | = | hub-hub discount |
| $W_{ij}$ | = | the amount of flow between *i* and *j* |
| $Z_k$ | = | 1 if node *k* is a hub, 0 otherwise |
| $X_{ijkm}$ | = | the proportion of flow from *i* to *j* that is routed via hubs *k* and *m*, respectively |
| $C_{ik}$ | = | travel cost between *i* and *k* |

This model simultaneously determines which nodes will serve as hubs and allocates non-hub nodes to the hubs. The objective function shown in Equation 6 minimises total network cost (as in the quadratic model). The constraint in Equation 7 requires that ρ hubs be open. The constraint in Equation 8 requires that all flow be routed via exactly one path; this means that every interacting pair (*i, j)* is allocated to a path via hubs k and *m*. The constraints shown by Equations 9 and 10 prohibit flow from being routed via a node that is not a hub. All flow must travel through at least one hub such that no direct connections are allowed between two non-hub nodes.

The model is computationally difficult to solve and, to date, optimal solutions are known only for very small networks (up to 25 nodes). The single-assignment model may be seen as a special case of the more general multiple-assignment model, since the optimal solution to a multiple-assignment model may result in single allocations for all nodes. For example, when the cost of travel across the hub-hub links is free, both the single and multiple-assignment models generate the same network design (O'Kelly et al., 1996).

Bryan and O'Kelly (1999) outline the variations of the UMAρHMP linearisation proposed by Ebery et al. (1998), who showed how the multiple-assignment problem may be modelled as a multiple commodity flow problem, while Klincewicz (1996) developed a heuristic for multiple assignment based on dual ascent and dual adjustment techniques for uncapacitated facility-location problems.

### 3.6.3 Shortest paths

In this method, the allocation problem of collecting and distributing flow can be solved by finding the shortest path between each pair of nodes in the directed graph, allowing collection from any node to any hub, transfer between hubs and distribution from any hub to any node. Ssamula (2006) proved that in route networks, the shortest path usually implies that the costs on the route are minimised, because of the ability to fly smaller aircraft which are cheap to operate on these routes.

Ebery et al. (1998) and Ernst and Krishnamoorthy (1996, 1998) solved the allocation problem involved in large numbers of possible sets of hub locations by using the all-pairs, shortest-paths method employed for multiple-allocation problems. The general methodology developed for finding the shortest paths is outlined below.

1. Partition the set of nodes into a number of clusters. In order for the lower bound to work well, these nodes should be geographically close together (i.e. with relatively small distances between them).
2. Assume we do not know the exact location of the hubs but only the number of hubs within each cluster, without knowing where in the cluster the hubs are located.
3. Calculate the shortest paths in a directed graph containing:
    a. Collection arcs from all nodes to any node in a cluster containing at least one hub.
    b. Distribution arcs from any node in a cluster containing at least one hub to all other nodes.
    c. Transfer arcs between nodes in different clusters if they each have at least one hub.
    d. Transfer arcs between nodes in the same cluster if the cluster contains at least two hubs.
4. Sum the product of flow volumes $W_{ij}$ and the shortest-path distances over all pairs of nodes $i$ and $j$ to obtain a lower bound of the minimum capacities.

5. The lower bound can be tightened by estimating the increase in cost if a particular node *i* in a cluster containing one or more hubs is in fact not a hub.

Branching simply occurs by sub-dividing a cluster and enumerating all possible node allocations between the sub-divisions of the cluster. Note that any lower bound for the multiple- allocation problem is also a lower bound for the single-allocation problem. In order to obtain a feasible single-allocation solution, further branching may be required to uniquely allocate a non-hub node to a hub node.

### 3.6.4 Clustering heuristics

Klincewicz (1991) used the clustering heuristics methodology as one of the methods for choosing hubs in the facility-location problem. The area was divided into clusters and the different airports were given indexes in terms of probabilities, using the principle that the airport in a cluster that is most suitable as a hub would be the airport with the shortest node-hub distances and the highest passenger demand. Matrices with data showing distances and passenger numbers to and from all the airports within the clusters are collected. Probability indexes are applied to each of these matrices such that for each origin airport:

- The destination node with the shortest distance from the origin will have the highest index of 1 for the distance matrix.
- The destination node to which the largest number of passengers from the origin node is flying has the highest index of 1 for the passenger matrix.

The indexes are totalled up for each node within the cluster that is a favourable destination as a hub in terms of:

- the node with the highest total index being the one with the shortest distance to all the nodes in the cluster
- the node with the highest total index being the one with the highest passenger flow to all the nodes in the cluster
- the node with the highest total index being most favourable in terms of both distances and passenger flow.

The hub with the highest total index will then be chosen as the most probable hub. The method of clustering was shown to have the advantage of narrowing down a search from a large number of nodes over a whole network to fewer nodes within a cluster, making it a more effective way of optimising the movement of flow.

### 3.6.5 Direct Vs non-stop services

One of the disadvantages of hubbing is the inconvenience of not having direct flights from one node to another. Aykin (1995) suggested that in a bid to improve service in air passenger transportation, more convenient non-stop flights can also be offered by the airlines between some non-hub cities. For each route, a decision regarding the service type is made such that flow between two cities is either shipped non-stop (direct shipping with no hub stop) or shipped through hub(s) (one or more hub stop).

Even though single-hub assignment has the advantages of network simplicity and possible higher facility utilisation, this may not be acceptable because of the operational restrictions it imposes on the system. Passengers may choose services that are more convenient rather than making one or more hub stops or having to take long detours every time they fly.

Aykin (1990) considered the discrete hub-location and routing problem with either the non-stop, the one-hub-stop or the two-hub-stop services for a hub network in which the hubs had already been located and their capacity was known. This procedure can be used to allow for flexibility especially if capacity problems do occur on some routes, causing hubs to reach their capacity for origins of high passenger demand. This procedure in turn allows for the hub-network to compete favourably with the traditional passenger airlines for these routes.

Aykin (1995) formulated the problem for location-allocation in which the hub locations or the service types are known. The problem is decomposed into a number of shortest-path problems involving service-type decisions if the hub locations are available. And if the service types are known, then the problem is reduced to a multi-facility location problem.

## 3.7 Summary

This summary is derived from the literature reviewed above on designing an H&S network, with particular application to the African region. The main aim of creating an H&S network is to minimise air transport costs over the vast African continent, which has sparse passenger demand. The network will focus on trying to consolidate passenger demand along the routes while transporting passengers from their origins to their destinations through hubs, which is one of the major benefits of the H&S network. The limitation of the design methodology is that the method for network design uses values that are manually input into a network cost equation from the cost model, thus the methodologies of heuristics, Tabu Search, Genetic Algorithms and linear programming cannot be used to find the optimum network.  In order to use the above-stated methodologies, automation of the cost model would be necessary, yet the advantage of this cost model is that it recalculates the most cost-effective option for each route in the network, in terms of operational and service parameters.

### 3.7.1 Hub location

The hub-location procedure will be taken as the ρ-hub median problem, where a fixed number of hubs (ρ) are chosen from *n* nodes, which are the airport locations. The hub-location problem will be solved using various methodologies with cost justifications. Africa faces the dilemma of not having many airports with the capacity and infrastructure for hubbing in terms of runways, gates and slots because of the low passenger demand and the number of flights operated. For the purpose of this study, the present airport capacity in terms of demand and infrastructure is ignored since the majority of African airports lack the proper infrastructure. As a first-cut analysis for Africa, the possible hub airports will be chosen based on the most suitable geographic location that would reduce the total network costs.

### 3.7.2 Node allocation

The node allocation will be solved as the Uncapacitated Single-Allocation ρ- Hub Median Problem, which implies that each node will be assigned to only one hub; this is done to limit the complexity of network cost calculations and operations. Furthermore, all nodes have to be routed via one hub, namely the hub with the closest distance to the node, to gain the benefits of flying short routes which use smaller aircraft which are cheap to operate.

### 3.7.3 Hub–and-spoke network

The total cost for the network is defined as the total cost of moving passengers from their origins to their destinations. The main approach in the literature to minimising the costs of transporting flow from origin to destination in an H&S airline network is that established by operational researchers who calculate the cheapest hub-location options that will lower network costs.

In this study, lowering the costs of the hub network will be carried out in two ways:

1. The total network costs will be minimised using the linear quadratic equation developed by O'Kelly et al. (1986) which was revised as shown in Equation 11 by Klincewicz (1991) to yield an equation that can be applied to larger, more complex networks so that the solutions can be evaluated more efficiently. The first part of Equation 11 calculates the node-hub costs, while the second part calculates the hub-hub costs:

$$\mathbf{f\,(x) = \sum_i \sum_k X_{ik}\, C_{ik}\, (O_i + D_i) + \sum_i \sum_k \mathit{X_{ik}} \sum_k \sum_m X_{\mathit{km}} \alpha\, C_{km}\, W_{km}} \qquad \textbf{Equation 11}$$

2. The lowest cost per passenger and the passenger numbers used in Equation 11 for each route in the network will be derived from the cost model developed by Ssamula (2004). The cost model calculates the operating costs incurred by flying along a specified route, and the database for this model contains Africa-specific data. The costs used are calculated by selecting the aircraft (chosen from 11 different aircraft types of varying capacity) most commonly used in Africa that produces the lowest operating costs for the route. A full description of the model is given in Chapter 4.

# CHAPTER 4: ROUTE COST MODEL

## 4.1 Introduction

This chapter summarises the development of the cost model used to calculate the route operating costs for an air transport service. The cost model in this study uses data specific to the African air network and its results are used to calculate the costs of the designed H&S network. The most relevant literature on the costing of an airline service is reviewed and used to compile an appropriate structure and cost components for a cost model. Thereafter, a discussion on the collection, compilation and validation of Africa-specific data, which include passenger demand and route distances, is presented. The development and calibration of the gravity model used to derive the passenger matrix used is described. The last section of the chapter applies the cost model to test the economies of scale achieved with increasing passenger demand and sector distances.

### 4.1.1 Background

The cost model calculates the operating costs and parameters, such as cost per passenger in a given sector, for 11 different aircraft. It allows the user to calculate the costs of running an air transport service. The costs calculated are based on minimum frequency to meet demand, using the most cost-effective aircraft and operational parameters. The cost model can be used to derive information for designing H&S networks because it has the following databases:

- 50-by-50 distance matrix for 50 African countries
- 50-by-50 origin-destination(O-D) passenger matrix for the 50 African countries

The cost model can then be used to calculate flow and costs per passenger along node-hub and hub-hub routes in order to derive the data needed to cost an H&S network.

### 4.1.2 Limitations of the model

1. The route cost model developed by Ssamula (2004) was based on referenced literature on the cost structure of airlines, available cost equations, default values and existing passenger numbers. Due to insufficient research in the area, some of the equations will have references as far back as 1973 because no new equations have since been developed. Equations pose a consitsent method of calculating costs irrespective of the area of operation.
2. The results of the costs model are neither deemed to be an accurate representation of the transportation costs nor realistic for airlines in the region. This is purely an academic exercise and therefore the results are more useful in analysing the cost differences through applying various network design methodologies.
3. Technicalities that exist in the airline industry as a business, which include bilateral service agreements, degrees of freedom permitted, airport capacity, available time slots, security and pollution, will not be taken into consideration.

4. The environmental costs of hub networks as explained by Morrell and Lu (2007) will not be taken into consideration when calculating the environmental costs created by an H&S network design.
5. The airline service being considered is a traditional passenger airline which transports its passengers to their destinations at the minimum frequency needed to meet existing demand. This is done irrespective of competition due to the insufficiency of the data needed to measure competition on African routes.

## 4.2 Model Development

### 4.2.1 Cost structure

Doganis (1989) states that the costing of an airline service is an essential input to many decisions taken by airline managers as to whether to run a service along a given route or whether the service will be making a profit or not. The way the costs are broken down and categorised will depend on the purpose for which they are being used. The operating costs of airlines are divided into operating and non-operating items which include the costs and not directly associated with airlines' own air services. The operating items are then further divided into direct and indirect operating costs. Direct operating costs include all costs that are dependent on the type of aircraft being operated and indirect costs include all the costs that have to be incurred irrespective of the aircraft type.

The cost structure that is adopted for the model is summarised in Figure 13. For this model, only the operating items were considered and sub-divided under the following headings:

- Standing (capital) costs of the aircraft
- Flying costs as a result of utilisation of the aircraft
- Other costs that are incurred while running the service.

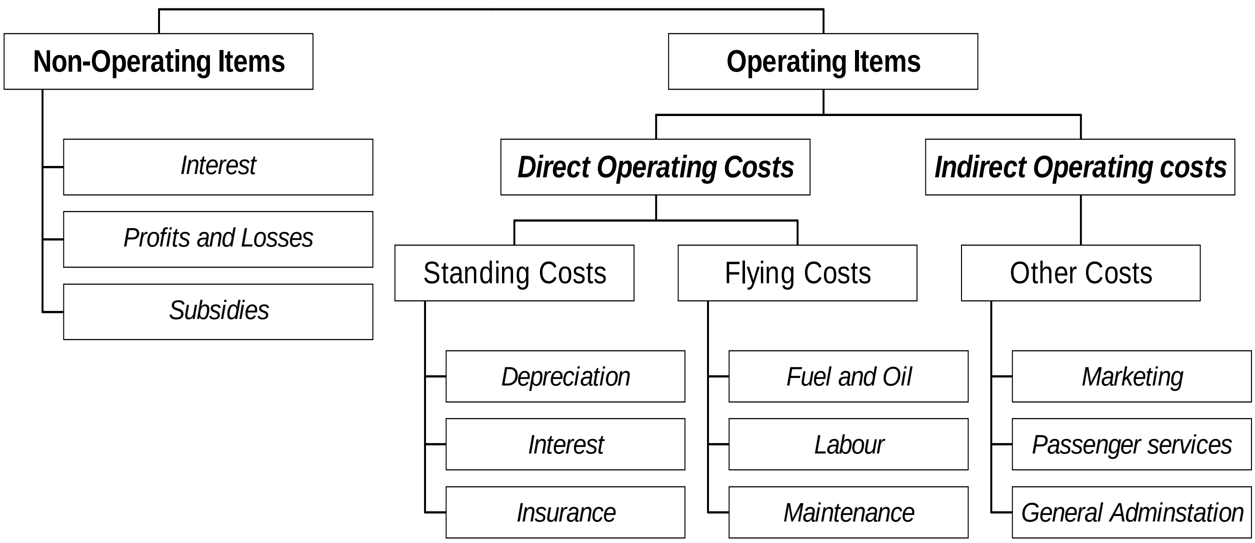



**Figure 13: Cost structure adopted for model**

The calculations for the direct operating costs, which include standing and flying costs, are calculated on the basis of the number of hours utilised annually, while the other costs are calculated as per unit description.

### 4.2.2 Standing costs

- *Depreciation* is defined as the charge an airline incurs for the expense of the flight equipment losing its value over time. The cost of depreciation per hour ($C_{Dep}$) can be calculated using the linear depreciation function shown in Equation 12 (from Stratford, 1973). The hourly depreciation cost of each aircraft in any one year can be established by dividing its annual depreciation cost by the aircraft's annual utilisation.

$$C_{Dep} = C_{total}\,(1-r_v)/L * U \qquad \textbf{Equation 12}$$

Where:

$C_{total}$ = Total cost of aircraft, engine and equipment

$r_v$ = Residual value as a proportion of the fully equipped aircraft and spares after the assumed life period (L years).

U = Average utilisation per aircraft in revenue block hours/year

- *Insurance* is an annual amount of money paid each year in case of any risks that may be incurred to the aircraft during its service life; these include fire, hijacking and theft. Doganis (1989) states that the insurance premium paid by an airline for each aircraft is calculated as a percentage of the full replacement price. The annual premium may range between 1,5 and 3% of the value of the aircraft, depending on a number of factors, including the airline, the number of aircraft it has insured and the geographical areas in which the aircraft operates. Stratford (1973) shows that the cost insurance per hour ($C_{Ins}$) on the total cost of equipped aircraft and spares, at a rate of x%, and annual utilisation U, is given by*:*

$$C_{Ins} = (x * C_{Total})\,/U \qquad \textbf{Equation 13}$$

Where:

$C_{total}$ = Total cost of aircraft, engine and equipment

x = Annual insurance premium rate

- *Interest rate* is defined as the cost of borrowing money; it is given as a percentage value which is applied to the outstanding loan. Since the airline industry is highly capital-intensive, this component should be included. The interest rate is set according to the prevailing economic conditions, such as inflation, bank lending rates and foreign exchange (forex) rates in the country where the loan is acquired. Since this study cuts across various countries with widely varying economic conditions, the interest rate chosen should be a more general rate, such as the rate at which the World Bank lends money for projects, taken as 8%.

### 4.2.3 Flying costs

- *Fuel and oil:* Doganis (1989) cites fuel as another major element in the cost of flight operations. The amount of fuel used up at the block time is given in terms of volume (US gal/h) and varies during climbing, descending and cruising. Fuel consumption is determined by engine thrust, specific fuel consumption (SFC), and the number of engines used for each of these manoeuvres. The volume of oil is also calculated per block hour at a ratio of 1:20 to the volume of fuel. The ATA (1963) uses a basic formula, shown in Equation 14, to calculate the cost of fuel and oil per block hour; this formula was updated by checking the constants factor of 1.02, which caters for the 2% factor of reserve fuel needed in emergencies and the 0,135 factor, which is the ratio of oil to fuel consumption when a plane flies. The costs of fuel used, in US$ per US gallon and oil in US$ per quart, are 0,933 and 0,233 respectively (Turbo Jet Technologies, 2003).

$$C_{ah} = 1{,}02\ (V_f * C_{ft} + 0{,}\ 135 * C_{ot} * V_o) \qquad \textbf{Equation 14}$$

  Where:

  $V_f$ = Block fuel volume (US gal/hr)

  $C_{ft}$ = Cost of fuel per US gallon

  $C_{ot}$ = Cost of oil for turbine engines per quart

  $V_o$ = Block oil volume (US gal/hr) = (1/20) * $V_f$

- *Maintenance:* The term ‘maintenance’ as presented in the ATA method includes labour and material costs for inspection, servicing and overhauling of the airframe and its accessories, such as engines, propellers, instruments and radio equipment. The relationship between the costs of components, as given by the US Department of Transport (Kane, 1996) and the ICAO (Doganis, 1989), shows that the maintenance costs amount to an average of 9,8% of the total operating costs of an airline service. This percentage value will then be used to obtain the value for maintenance.

- *Crew costs:* The flight crew costs include all costs associated with the flight and cabin crew, including allowances, pensions and salaries. They are usually the largest element in operating expenses. In 1963 the ATA derived crew costs from a review of several representative crew contracts; based on speed and the ToGWmax, the equation is converted to metric units, as shown in Table 4. Even though this equation is from 1963, it provides a more standardised way of calculating labour costs because the market research shows inconsistent methods of calculating crew costs, which change for each country and airline.

**Table 4: Crew costs per hour (US$/flight hour)**

| **Engine Type** | **International planes** |
|---|---|
| | **Three-man crew** |
| **Turbo Jet** | [0,0000225ToGWmax + 200] |
| | **For each additional member** |
| | + [35] |

Source: Stratford, 1973

### 4.2.4 Other costs

- *Landing and parking fees:* These fees are included as an operating expense and are of significance in actual and comparative aircraft cost estimates (Stratford, 1973). They are based on the gross weight of the aircraft, but there are a number of exceptions to this and international flights and short-sector flights are, in some cases, liable for special rates for landing fees. Parking fees are also charged according to the weight of the aircraft per 24-hour period, after a specific time period.
- *Passenger fees:* Airport charges include a charge for handling passengers in proportion to the number of passengers disembarking from an aircraft (Doganis, 1989). At present, most airports collect a fee directly from the passengers, termed the ‘airport tax’, which is included in the fare paid by the passengers.
- *Ticketing, sales and commissions*: These encompass the charges associated with ticketing, sales and promotion activities, as well as all office and accommodation costs arising throughout these activities. The percentage of costs that are allocated to ticketing, sales and commissions amounts to 15,5% of the indirect operating cost (Doganis 1989).
- *General administration*: The percentage entailed for administration is about 6,1% of airlines’ indirect operating costs; this will be used to calculate the cost of general administration (Doganis, 1989).

### 4.2.5 The input component

The route cost model was developed in a spreadsheet format with an input component. In this component, the user has the option to specify the basic descriptors of the route, for which the operating costs are to be calculated. The user needs to specify the origin and destination countries for the airline service that is being costed. An automatic link gives the default values of ***sector distance*** and the ***weekly passenger demand*** from the databases, for the corresponding airports of the countries. The user also has the option of manually inserting user-specified values in the section provided. From these route descriptors, the model calculates the ***minimum service frequency***, which is the minimum number of flights required to meet the weekly passenger demand on that route and also allows for user-specified variables to be input. The aircraft default values and aircraft technical specifications, which also serve as input to the model, are included in the ***aircraft database***.

### 4.2.6 The calculation component

The purpose of this component is to calculate the operating costs for each of the 11 different aircraft types, for the route specified. Most of the cost calculations are based on the number of hours utilised. ***Utilisation*** is defined as the average period of time for which an aircraft is in use on a particular route. It is calculated from the ***block time*** from ‘engine-on’ to ‘engine-off’ of the aircraft, the ***round-trip time*** and the ***maximum flight frequency*** that a single aircraft can fly on this route weekly. The ***fleet size*** is calculated depending on whether the ***maximum flight frequency*** of one aircraft can meet the ***minimum flight frequency*** needed to meet existing demand. Once the utilisation hours, fleet size and block time for the route have been specified, each of the ***cost components*** is calculated using the default values, equations and aircraft specifications for each aircraft type.

### 4.2.7 The output component

This component gives the total costs of running an aircraft on the route for a particular flight and for weekly flight frequency. It also gives the total costs for the total fleet on the route for the different aircraft types, both weekly and annually. The cost-related parameters for running the service are then calculated. Graphic outputs of the cost-related parameters are also given. All the aspects of route service design that are key to lowering the variable operating costs, including frequency of flights, sector length, block time and cheapest aircraft type, are given in this component.

### 4.2.8 Model description

Figure 14 is a flow chart illustrating the layout of the route cost model for aircraft operations, with its different components. It shows the information that is required to obtain the outputs needed and the step-by-step procedure of the calculation of costs carried out at each stage.

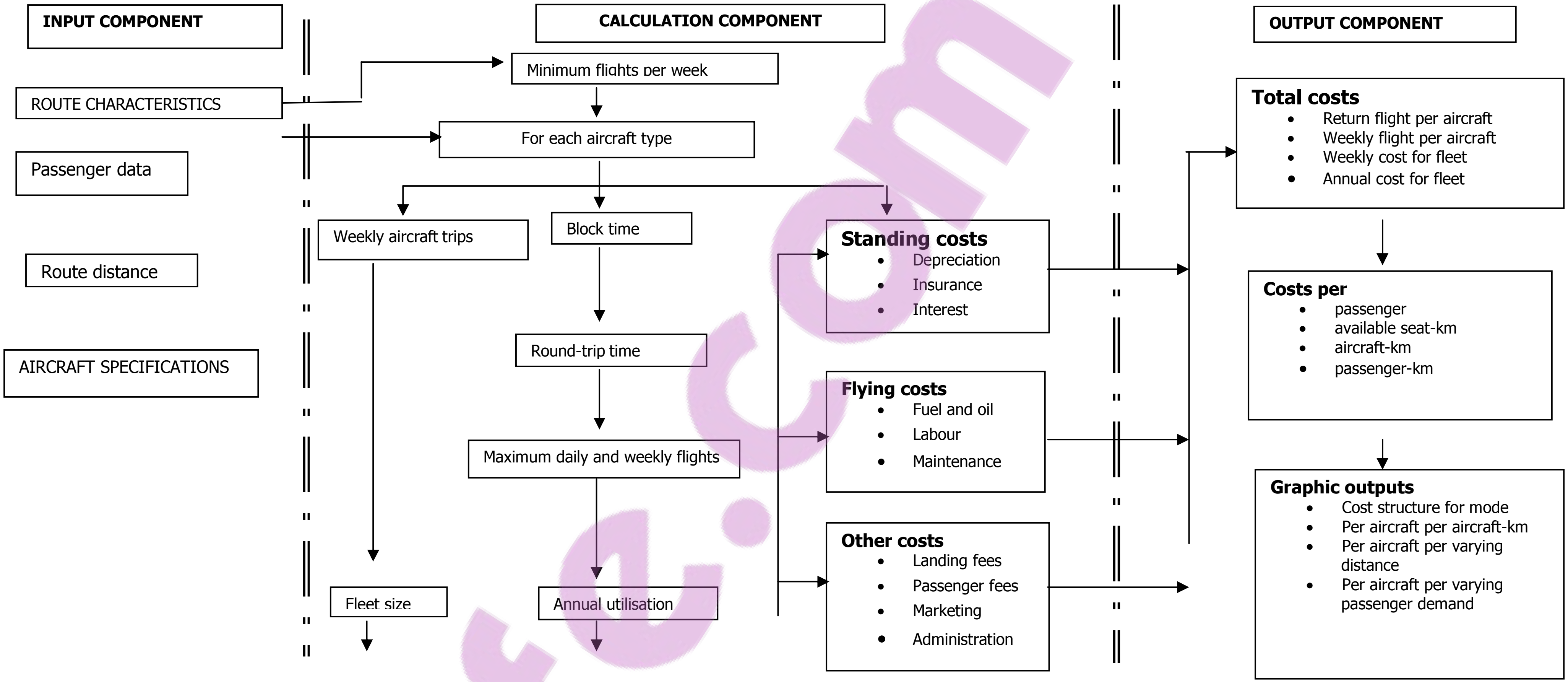



**Figure 14: Flow chart of the cost model**

## 4.3 Data Collection

This section describes the data sourcing, collection and validation process that is used to populate the datasets needed in the cost model. These data include the default values, aircraft specifications, sector distances and passenger data. The cost model requires datasets for distances and passengers for each O–D pair within Africa so as to calculate the costs of running a service along any of these routes.

### 4.3.1 Default values for the route cost model

The default values used in the calculations needed to develop the route cost model are listed in Table 5 and specified and referenced accordingly.

**Table 5: Default values used in the model**

| ITEM | DEFAULT VALUE | REFERENCE |
|---|---|---|
| Depreciation period (L) (years) | 9 | Doganis (1989) |
| Residual value ($r_v$) (%) | 10 | Doganis (1989) |
| Interest rate (%) | 8 | World Bank (2003) |
| Insurance rate (x) (%) | 2 | Doganis (1989) |
| Ground manoeuvre time (h) | 0,25 | ATA (1963) |
| Air manoeuvre time (h) | 0,10 | Kane (1996) |
| Service and refuelling time (h) | 0,90 | Kulula airlines (2003) |
| Usable hours in a day | 14 | Stratford (1973) |
| Operating weeks in a year | 52 | Stratford (1973) |
| Cost of fuel (US$/US gal) | 0,933 | Turbo Jet Technologies (2003) |
| Cost of oil (US$/quart) | 0,233 | Turbo Jet Technologies (2003) |
| % of pass demand flying within Africa region | 15 | AFRAA (2000) |

### 4.3.2 Aircraft type-specific data

In order to calculate the cost of running an aircraft, the technical aircraft specifications needed are collected from the various sources shown in Table 6. The cost model uses the 11 types of aircraft in Table 7 commonly used for airlines within Africa; these are from data derived through the Air-Claims CASE Database (2000).

**Table 6: Data sources**

| COLLECTED DATA | SOURCE |
|---|---|
| Aircraft specifications | Janes' World Aircraft (Jackson, 1997) |
| Engine specifications | Jenkinson et al. (2001) |
| Capital cost of aircraft (US$ million) | Pyramid Media Group website (2000) |
| Fuel consumption (US gal/h) | Rolls Royce (2003) |
| Oil consumption (US gal/h) | Rolls Royce (2003) |
| Passenger service charge (US$/passenger) | NDoT, South Africa (1998) |
| Landing fees (US$ /single landing) | NDoT, South Africa (1998) |
| Parking fees (US$/24-hour period) | NDoT, South Africa (1998) |

**Table 7: Technical specifications for model aircraft types**

| SPECIFICATIONS | EMBRAER Erj 135 JET | FOKKER F 50 | BOEING 737-200 | BOEING 737-400 | AIRBUS A320-200 | AIRBUS A340 200 | BOEING 737-800 | BOEING 767-200 | BOEING 747-200 | BOEING 747-300 | BOEING 747-400 |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Cruising speed | 833 | 448 | 760 | 815 | 833 | 861 | 810 | 850 | 895 | 897 | 914 |
| Passenger capacity | 37 | 56 | 130 | 168 | 180 | 295 | 189 | 255 | 291 | 411 | 401 |
| ToGWmax (tonnes) | 21 100 | 19 950 | 52 437 | 68 040 | 73 500 | 27 500 | 78 240 | 136 080 | 374 850 | 377 800 | 390 100 |
| Max fuel capacity (gallons) | 5187 | 1 357 | 5 163 | 5 701 | 6 300 | 36 984 | 6 878 | 24 179 | 53 858 | 53 858 | 57 284 |
| Engine type | AE3007 | PW125B | JT8D-7 | CFM 56-3B1 | V2500-A1 | CFM56-5C2 | CFM56-7B20 | RB211-524H | RB211-524D4 | Trent 600 | RB211-524H |
| Thrust (Ibf) | 7 400 | 5 000 | 14 000 | 20 000 | 25 000 | 31 200 | 21 000 | 59 500 | 53 000 | 68 000 | 59 500 |
| Cruise SFC (lb/lbf h) | 0,36 | 0 ,32 | 0 ,585 | 0 ,38 | 0 ,35 | 0 ,32 | 0 ,38 | 0 ,373 | 0 ,373 | 0 ,45 | 0 ,373 |
| Maximum range (km) | 3 019 | 1 300 | 3 700 | 3 810 | 5 615 | 13 500 | 5 670 | 12 250 | 7 900 | 7 700 | 13 480 |
| Number of engines | 2 | 2 | 2 | 2 | 2 | 4 | 2 | 2 | 4 | 4 | 4 |
| Number of crew | 5 | 5 | 6 | 7 | 7 | 8 | 7 | 7 | 8 | 8 | 8 |

Source: Jackson, 1997

### 4.3.3 Distance matrix

The one-way distance between each of these airports is collected from an on-line airport mileage calculator and the distance is calculated. This was done for each of the airports to create a 50-by-50 distance matrix in kilometres.

### 4.3.4 Trip generation

The gravity model used to create an O-D passenger matrix is based on 50 nodes, a single node in each of the 50 countries within the African continent. Each of 50 countries is represented by one major international airport per country that is used as a node within the African network. The sources and values used in the development of the O-D passenger matrix for each of the African countries are discussed below:

- World Bank Data Query, an on-line database, provides information on development indicators for World Bank member countries. It is used to derive the indicators, which include population, gross domestic product (GDP) (in US$) and aircraft departures per year, for the year 2001, and are shown in Table 8.
- The AFRAA Annual Report (2000), which gives data on African airlines departures, shows the average percentage number of passengers that fly to destinations within Africa as 15%.
- From the aircraft types shown in Table 7, the average seat capacity is calculated as 219, which is rounded off to 200.

- The load factor, which is the ratio of the revenue passenger kilometres (RPK) to the available seat kilometres (ASK), for African airlines is calculated by Chingosho (2005) to be as low as 62,56%, as shown in Figure 2.

The number of trips within the continent from each country are calculated from the product of the aircraft departures, the percentage of flights within Africa (15%), the average aircraft seat capacity (200) and the load factor (0,626).

**Table 8: GDP, population and aircraft departures for 2001**

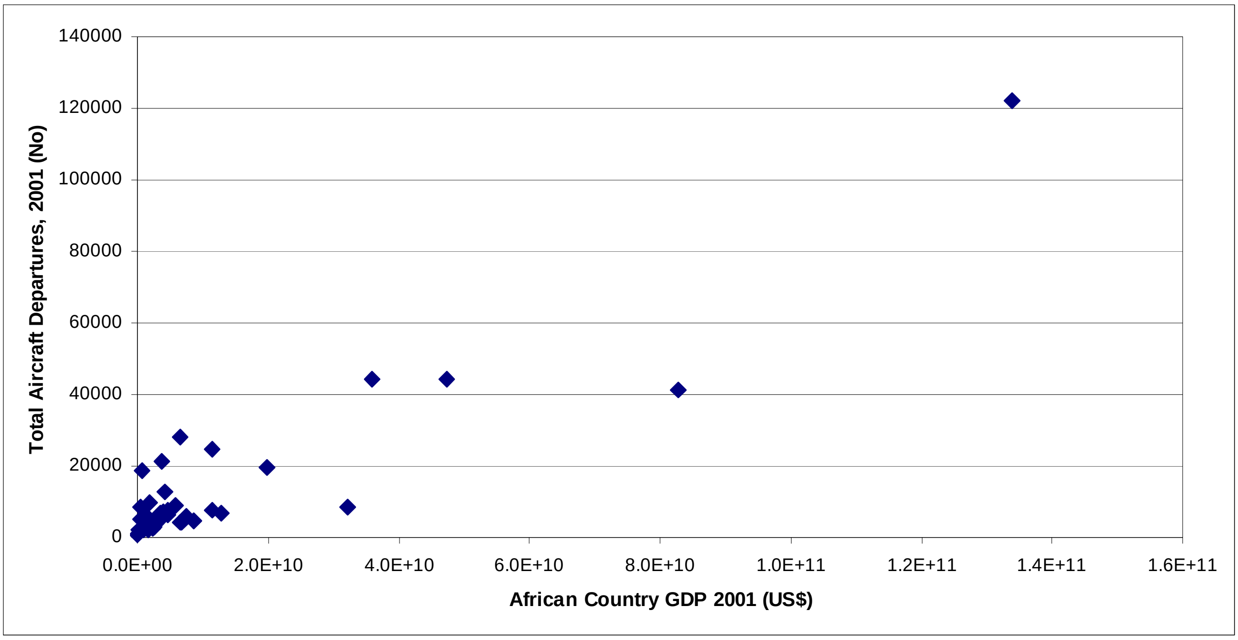
| Name of Country | GDP Per Capita (US$) | GDP (US$) | Population | No. of Annual Aircraft Departures |
|---|---|---|---|---|
| **Algeria** | 1 605 | 47 356 990 000 | 29 507 000 | 44 200 |
| **Angola** | 520 | 6 445 192 000 | 12 401 580 | 4 400 |
| **Benin** | 381 | 2 269 305 000 | 5 950 330 | 2 400 |
| **Burkina Faso** | 232 | 2 485 295 000 | 10 730 330 | 3 119 |
| **Burundi** | 134 | 877 847 300 | 6 548 190 | 3 121 |
| **Cameroon** | 611 | 8 703 117 000 | 14 238 860 | 4 700 |
| **Cape Verde** | 1299 | 539 518 000 | 415 320 | 8 7000 |
| **Central African Republic** | 291 | 1 047 204 000 | 3 603 400 | 2 800 |
| **Chad** | 233 | 1 693 364 000 | 7 282 870 | 2 183 |
| **Congo, Democratic Rep.** | 684 | 1 949 821 000 | 2 850 060 | 9 900 |
| **Cote d'Ivoire** | 843 | 12 782 400 000 | 15 159 110 | 6 800 |
| **Egypt, Arab Rep.** | 1 343 | 82 703 660 000 | 61 580 000 | 41 400 |
| **Equatorial Guinea** | 1 053 | 455 800 100 | 433 060 | 5 172 |
| **Ethiopia** | 106 | 6 515 568 000 | 61 266 000 | 28 100 |
| **Gabon** | 3 957 | 4 618 957 000 | 1 167 290 | 7 500 |
| **Ghana** | 405 | 7 474 019 000 | 18 449 370 | 5 900 |
| **Guinea** | 506 | 3 588 601 000 | 7 086 120 | 6 978 |
| **Guinea-Bissau** | 179 | 205 559 200 | 1 149 330 | 2 183 |
| **Kenya** | 398 | 11 444 030 000 | 28 726 000 | 24 700 |
| **Madagascar** | 256 | 3 738 635 000 | 14 592 380 | 21 200 |
| **Malawi** | 176 | 1 736 504 000 | 9 884 000 | 4 700 |
| **Mali** | 261 | 2 699 381 000 | 10 333 640 | 3 800 |
| **Mauritania** | 402 | 1 002 265 000 | 2 493 120 | 2 200 |
| **Mauritius** | 3 575 | 4 146 256 000 | 1 159 730 | 12 800 |
| **Morocco** | 1 290 | 35 817 410 000 | 27 775 000 | 44 300 |
| **Mozambique** | 228 | 3 873 405 000 | 16 965 000 | 7 300 |
| **Namibia** | 2 028 | 3 411 185 000 | 1 681 820 | 5 100 |
| **Niger** | 205 | 2 076 744 000 | 10 120 120 | 3 322 |
| **Nigeria** | 266 | 32 143 820 000 | 120 817 300 | 8 400 |
| **Sao Tome and Principe** | 288 | 40 824 040 | 141 700 | 1 000 |
| **Senegal** | 514 | 4 645 699 000 | 9 032 380 | 6 500 |
| **Seychelles** | 7 657 | 603 741 100 | 78 850 | 18 900 |
| **South Africa** | 3 231 | 133 767 700 000 | 41 402 390 | 122 300 |
| **Sudan** | 383 | 11 479 730 000 | 29 978 890 | 7 600 |
| **Swaziland** | 1 334 | 1 321 043 000 | 990 460 | 2 000 |
| **Tanzania** | 267 | 8 591 175 000 | 32 128 480 | 4 500 |
| **Togo** | 333 | 1 416 300 000 | 4 258 140 | 5 900 |
| **Tunisia** | 2127 | 19 850 090 000 | 9 333 300 | 19 400 |
| **Uganda** | 322 | 6 777 215 000 | 21 040 000 | 4 200 |
| **Zambia** | 335 | 3 237 580 000 | 9 665 710 | 4 900 |
| **Zimbabwe** | 472 | 5 731 721 000 | 12 153 850 | 8 800 |

Source: World Bank, 2003

#### 4.3.4.1 GDP versus air travel

To test the validity of the passenger demand data derived for Africa, the elastic relationship between air travel and GDP will be investigated for the dataset in Table 8. GDP is a measure of the economic well-being of people within a nation, and it is therefore assumed that the higher the GDP, the greater the output of goods and services, the better off people are, and the more they will travel for business, personal and pleasure reasons (Taneja, 1978). The GDP of countries has always been linked to air travel in such a way that the more the country earns, the higher the air travel, and it has been proved that the average growth of air traffic is double that of GDP (Chingosho, 2005). Hanlon (1999) also states that although air travel tends to grow faster than GDP, it still follows very closely the cyclical pattern in GDP. Economic activity and the highest number of aircraft departures (as seen from Table 8) on the African continent is currently concentrated among a few countries, which include South Africa, Nigeria, Egypt, Morocco and Algeria, which account for two thirds of the continent's GDP and 43% of the air travel on the continent.

Figure 15 shows the relationship between GDP and aircraft departures for 41 African countries. The skew demand distribution is very evident. The number of departures is clustered towards the lower end of the demand, due to the generally sparse air travel in Africa. Sparse markets are not necessarily uniformly thin, but can be dominated by a few very strong nodes. In Africa's case, this dominance comes from five countries: South Africa, Nigeria, Egypt, Morocco and Algeria together account for 67% of the continent's combined Gross Domestic Product (GDP) and 43% of its air travel (World Bank, 2003). This is significant from a hub design perspective. It immediately suggests that airports in the dominant countries are promising candidates for regional hubs.




Source (World Bank, 2003)

**Figure 15: Graph showing African GDP and aircraft departures**

#### 4.3.4.2 Data validation

In order to validate the data used for aircraft departures in Africa, an alternative data source is sought and using statistical analysis tests such as the f-test, a simple linear regression analysis is carried out on the two datasets. The alternative dataset for aircraft departures from African countries is supplied by IATA data for the year 2001 shown in Table 9.

**Table 9: Aircraft departures from African countries in 2001**

| Country | IATA | World Bank | Country | IATA | World Bank |
|---|---|---|---|---|---|
| Algeria | 49 600 | 44 300 | Malawi | 3 600 | 4 700 |
| Angola | 7 300 | 4 400 | Mali | 1 500 | 3 800 |
| Benin | 1 500 | 2 400 | Mauritania | 4 900 | 2 200 |
| Botswana | 7100 | 7 300 | Mauritius | 11 000 | 12 800 |
| Burkina Faso | 1 800 | 3 119 | Morocco | 35 100 | 44 300 |
| Burundi | 1 400 | 3 121 | Mozambique | 4 600 | 7 300 |
| Cameroon | 6 500 | 4 700 | Namibia | 7 400 | 5 100 |
| Cape Verde | 14 600 | 8 700 | Niger | 1 500 | 3 322 |
| Central African Republic | 1 500 | 2 800 | Nigeria | 6 400 | 8 400 |
| Chad | 1 800 | 2 183 | Sao Tome and Principe | 800 | 1 000 |
| Congo, Democratic Rep. | 10 200 | 5 200 | Senegal | 4 800 | 6 500 |
| Cote d'Ivoire | 3 500 | 6 800 | Sierra Leone | 100 | 2 000 |
| Egypt, Arab Rep. | 41 600 | 41 400 | South Africa | 102 200 | 122 300 |
| Equatorial Guinea | 600 | 5 172 | Sudan | 5 500 | 7 600 |
| Ethiopia | 28 100 | 28 100 | Tanzania | 6 000 | 4 500 |
| Gabon | 10 000 | 7 500 | Togo | 1 500 | 5 900 |
| Ghana | 3 500 | 5 900 | Tunisia | 17 200 | 19 400 |
| Guinea | 700 | 6 978 | Uganda | 900 | 4 200 |
| Guinea-Bissau | 1 200 | 2 183 | Zambia | 1 200 | 4 900 |
| Kenya | 19 600 | 24 700 | Zimbabwe | 17 700 | 8 800 |
| Madagascar | 16 800 | 21 200 | | | |

The statistical analysis show that the linear regression analysis results, which should be as close as possible to 1 for the datasets, gives an $R^2$ of 0,97, forming a linear equation with a slope of 1,108. The correlation coefficient between the two datasets is 0,98, which is very good because it is close to 1. The results show s the validity of World Bank dataset, which provides the most comprehensive sources of data, is usable.

### 4.3.5 Trip distribution

The trip distribution is developed using Furness's method of a double-constrained gravity model, using the trips generated in Section 4.3.4. The trip distribution step involves the development of the 50-by-50 O-D passenger matrix that will be used to calculate the number of people who travel between each O-D pair. The justification for using this method is that passenger data from each O-D pair are very difficult to collect. This highlights one of the major limitations of this research work, namely the lack of available and comprehensive data because of the competitive nature of the airline industry. The formula for the double-constrained gravity model given by Ortúzar & Willumsen (1994) is:

$$T_{ij} = A_i B_j O_i D_j d_{ij}^{-\beta}$$

Where:

$T_{ij}$ = trips between countries i and j

$O_i$ = total number of trips originating from country i

$D_j$ = total number of trips with destinations to country j

$$A_i = \left( \sum_i B_j D_j d_{ij}^{-\beta} \right)^{-1},$$

$$B_j = \left( \sum_i A_i O_i d_{ij}^{-\beta} \right)^{-1}$$

β = calibration parameter

The term $B_j$ ensures that the two constraints $\sum_j T_{ij} = O_i$ and $\sum_i T_{ij} = D_j$ are satisfied. This is done by alternately calculating the value of $A_i$ and $B_j$ by iteration until the conditions are satisfied.

The model is developed as follows:

- A 50-by-50 matrix of the values ($d_{ij}^{-\beta}$) is built, where $d_{ij}$ is the distance between countries i and j.
- Then, with these values, we can calculate the resulting total trips and expand each cell in the matrix by a ratio derived from dividing the sum of the trips $O_i$ or $D_j$ by $\sum \left( d_{ij}^{-\beta} \right)$.
- This produces a matrix of base trips, which is adjusted to match the trip end totals, assuming that the total trips on a sector are independent of the direction of flow.

The calibration of the gravity model is carried out to make sure that the model comes as close as possible to the base-year trip patterns. The parameters $A_i$, $B_j$ and β are used, where $A_i$ and $B_j$ are calibrated during the estimation of the gravity model in order to satisfy the constraints. The values of β, which in the first iteration gives values that come as close as possible to the total departures, are 0,1 and 0,14. The β value of 0,14 is then chosen because its iterations satisfy the end conditions given by the total trips $O_i$ and $D_j$.

Formal validation of the data in the O-D matrix was not carried out because of the lack of available and reliable data about the passenger numbers flying within Africa between O-D pairs. The reasons for this include:

1. The numbers of people who in reality fly between an O-D pair on a given network include direct, connecting and transiting passengers because of the lack of availability of direct flights.
2. Even though inferences can be drawn about the demand for a given airline on a route – based on frequency of service, load factors and aircraft type – such inferred data would be inaccurate because this method would neglect the market share carried by competition airlines on the same route.
3. Furthermore, the effect of competition on a given route within the African scenario cannot be assumed as the available data on the number of airlines that operate on certain routes are limited.

## 4.4 Application of the Cost Model

The cost model developed allows the user to make an informed choice as to the least costly aircraft type, the lowest operating costs, the most highly utilised fleet size and the most efficient service operations. This section applies the model to test the effectiveness of consolidating passengers in lowering the operating costs on a route and to test the effect of the economies of scale on the aircraft choice as distances increase.

### 4.4.1 Testing economies of traffic density on a route

Doganis (2001) states that economies from route traffic density arise because the higher seat load factors lower the costs per passenger mile. The cost model is then applied to calculate the cost per passenger as the weekly passenger numbers increase on a 3 000 km route for the 11 different aircraft used in the model.

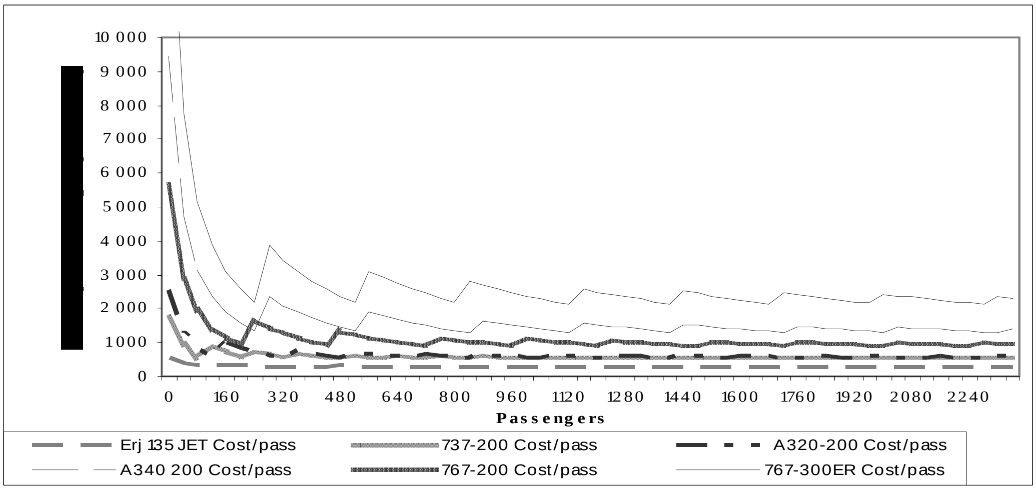



**Figure 16: Exponential decrease of costs with increasing number of passengers**

The results of the model for costs per passenger are representative of the operating costs for this route. The model does not take into account the competition practices, such as predatory pricing and price discrimination, that occur in the airline industry.

Figure 16 confirms the general trend of exponential decrease in operating costs per passenger as demand increases as the cost of operating the flight is spread over more passengers. The kinks in the curves occur when the fleet size has to be increased in order to meet demand. Most economies of scale are seen to occur above 250 passengers a week. This is because the operating costs of flying aircraft at low seat load factors outweigh the fixed costs of operating the flight. The cheapest aircraft for this flight is the 37-seater Erj 135 Jet as it is seen to have the lowest costs per unit flow because it is a cheap aircraft to operate. The advantage of consolidating passengers on short routes can be seen in this application. This type of route enjoys both the economies of scale and the advantage of flying cheap short-range aircraft.

### 4.4.2 Effect of economies of scale on aircraft choice as distances increase

The cost model is applied to investigate the change in costs per passenger with increasing passenger demand and distances. The general trend of economies of scale is seen in Figure 16 as the annual passengers increase, while the following observations are made from the graphs shown in Figure 17:

- Generally, as distances increase, the costs per passenger increase as well, due to the increasing operating costs incurred with higher aircraft utilisation costs in terms of depreciation, fuel and labour. This means that in order to ensure low operating costs, the sector distances flown should be kept as short as possible.
- The Embraer 135 jet, which is the cheapest aircraft to fly for 30 000 annual passengers, as shown in Figure 18A, becomes the most expensive option as the passenger numbers increase, as shown in

Figures 18 C and D. This is because the 37-seater aircraft requires a larger fleet size to transport the same number of passengers as compared with the 100–200-seater aircraft.

- There is a set of planes that fly cheaply even when passenger demand increases, unlike the Embraer 135 jet. These planes include the Boeings737-200 and 737-800, and the airbus A320-200 and A340-200, which remain cheap options as passenger numbers increase, as shown in the graphs in Figure 17.
- Aircraft are limited by range, which implies that the most appropriate aircraft type for a route in terms of costs is determined by the sector distance. This is demonstrated in Figure 18C where the lowest average costs per passenger for a 5 800 km route are just below US$80. On any route longer than that the average cost per passenger jumps to about US$120 because the cheaper aircraft cannot fly the route.

The relationship between distance and cost for a given craft is linear because depreciation, fuel, and labour increase with flight time or distance. This finding is similar to Swan and Adler's (2006). However, these authors estimated two continuous Cobb-Douglas functions to represent the optimal cost performance for regional and long-haul distances, based only on Boeing and Airbus jets. We cover a larger range of aircraft types which are suited to the very low density routes found in Africa, and explicitly include each craft's range in the calculation. This brings out important discontinuities that may affect network design in sparse markets. When looking at the lower cost envelope in each graph, discontinuities appear around the range limits of each plane.

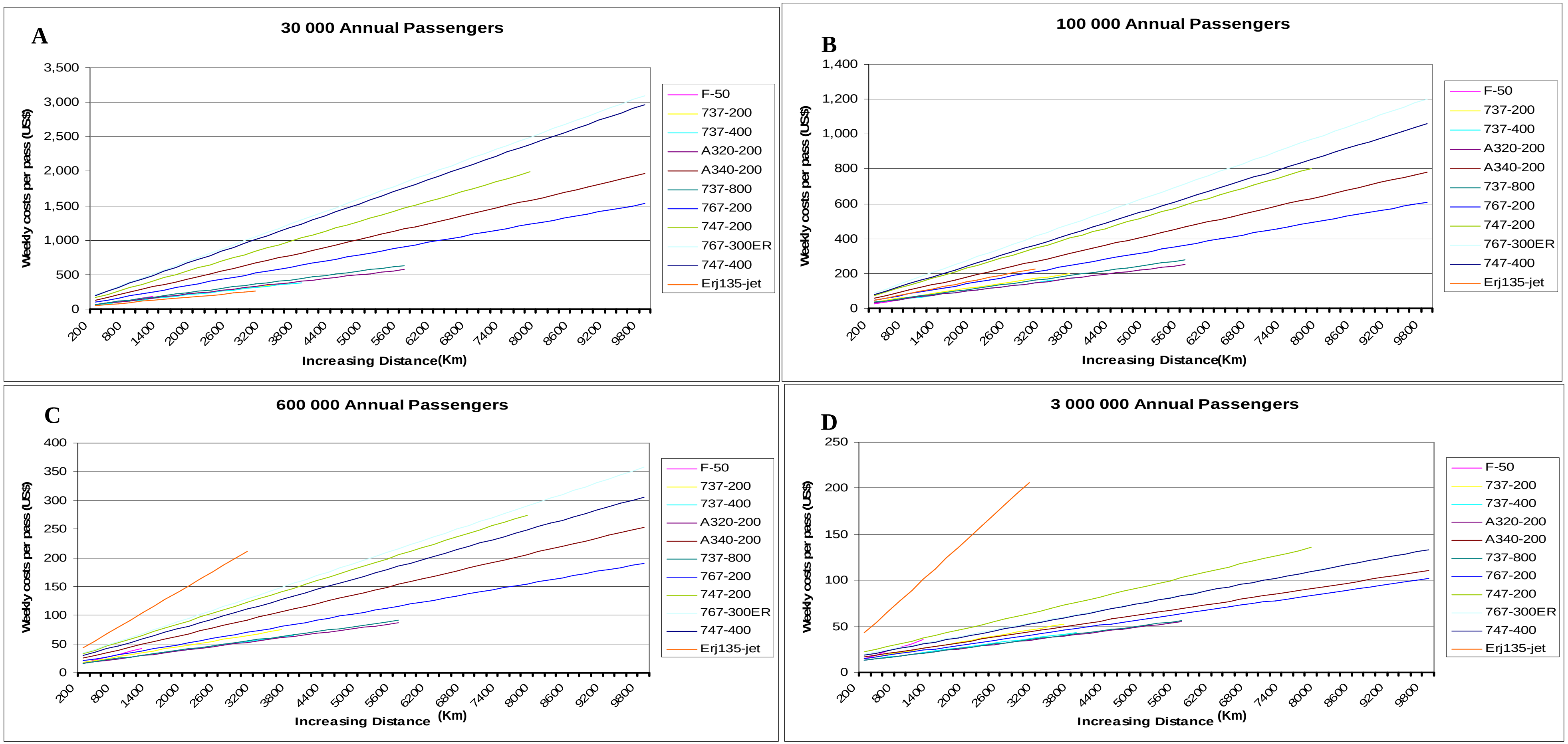



**Figure 17: Graphs showing unit costs as distances and passenger numbers increase**

A general observation from the application of the cost model to hubbing is that the economies of scale that are enjoyed with increasing passenger demand increase with the sector distance. Furthermore, above a certain threshold, the sector distances can increase operating costs greatly because of the different aircraft that can fly that sector. Figure 18 below illustrates this point. It shows a three-hub network, with the same number of passengers on each link and the total inter-hub distances for both networks at 12 000 km. The two networks differ by having two competing hub options, C and D, for networks 1 and 2 respectively, which in Figure 18 are seen to be an average of 5 800 km.

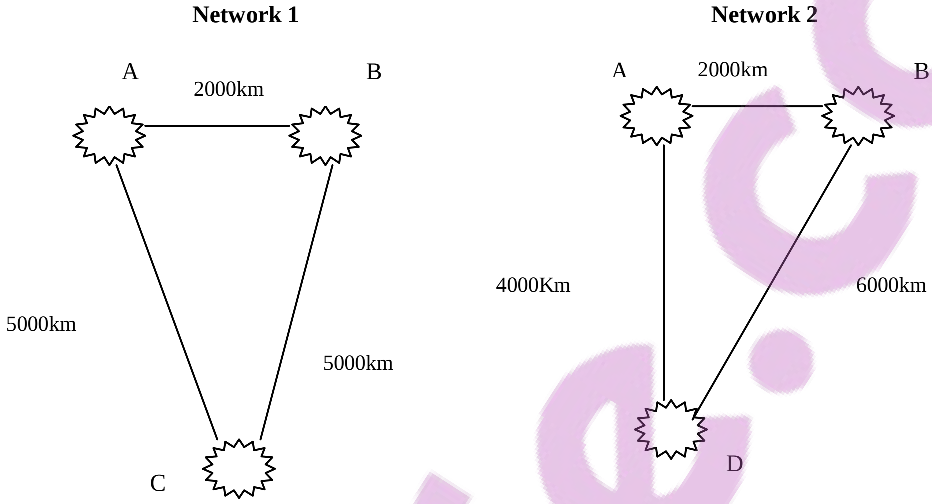



**Figure 18: Route parameters for different networks with competing hubs**

**Table 10: Network costs (in US$) for networks shown in Figure 18**

| | NETWORK 1 | | | NETWORK 2 | | |
|---|---|---|---|---|---|---|
| **Link** | **AB** | **BC** | **AC** | **AB** | **BD** | **AD** |
| **Aircraft type** | A320-300 | A320-300 | A320-200/737-800 | A320-300 | 767-200 | A320-300 |
| **Flow** | 1 475 387 | 2 343 594 | 1 420 803 | 1 475 387 | 2 343 594 | 1 420 803 |
| **Cost per pass( US$)** | 46 | 78 | 83 | 46 | 110 | 70 |
| **Operating costs (US$)** | 67 867 802 | 182 800 332 | 117 926 649 | 67 867 802 | 257 795 340 | 99 456 210 |
| **Network costs (US$)** | 368 594 783 | | | 425 119 352 | | |

The distances between hubs, the aircraft type and the costs per passenger for each link shown are summarised in Table 10. The costs per passenger on link BC at 5 000 km as compared with link BD at 6 000 km are higher by U$32 due to the use of different aircraft which can operate on the 6 000 km link. Furthermore, link AD, which is 1 000 km shorter than link AC, results in an 18% reduction in the costs per passenger. This proves that sector distances affect the aircraft type that may be used on the route. This, in turn, increases total inter-hub network costs by 15%. Therefore, in hub network design, two competing hub locations with different sector distances above and below a certain threshold range can have different operating costs because of the aircraft type flown. Medium- and long-haul aircraft are more expensive to operate and can therefore greatly increase network costs. Therefore, when designing a cheap hub network, shortening the sector distances allows for economies of scale while using short-range, cheaper aircraft.

# CHAPTER 5: HUB NETWORK DESIGN

## 5.1 Introduction

The major aim of this chapter is to assess the different methodologies used for hub location and node allocation to lower the hub-and-spoke (H&S) network costs for Africa. This chapter will introduce the approach that is used to design hub networks in this study. It involves, first, locating the hub airports through which all the flow will pass. Once the hubs have been located, the nodes are allocated to the hubs using single assignment to the closest hub. Thereafter the pattern of flow for the network is established and the passenger numbers along each link are calculated. The network is then costed by calculating the cost of transferring all the passengers from their origins to their destinations through the hub link.

The hub network design is based on different hub-location strategies for Africa, including a one-hub network, clustering, node-hub analysis and the geo-political method.

## 5.2 Africa Defined as a ‘Sparse’ Network

Africa is a large continent of 30 million km$^2$, with dimensions three times the size of Europe and distances from the south to the north of about 8 000 km. Although the population of the continent is over 860 million, the average population density of Africa is 28 inhabitants per km$^2$, which falls below the world’s average population density of 44 persons per km$^2$, thus defining the continent as a sparsely populated region. In 2002, Africa’s population comprised 13% of the world’s total. Africa’s air passenger traffic contributed only 4,1% to the world’s total air passenger traffic, making it the smallest region for air services worldwide. (Chingosho, 2005) The passenger data used in this study show that the annual number of air trips per inhabitant in Africa is equal to only 0,14.

Africa’s air network characteristic of low passenger demand and the vastness of the continent will make designing a hub network a challenge.  The justification for designing a cost-effective hub network is that Africa shows great potential since air traffic within the continent is expected to grow significantly, spearheaded by the open skies initiative adopted in the Yamoussoukro Decision (YD), under the auspices of the African Union and NEPAD (Chingosho, 2005).

## 5.3 Design Approach

The approach used when designing an H&S network is as follows:

### 5.3.1 Locational analysis

Locational analysis is a procedure in operational research used to locate the hubs and route flow via the hubs in an H&S network system. The two systems defined by O’Kelly and Bryan (1998) are:

1. *A delivery system*, in which the decision-maker positions the facilities and determines the rules of allocation to the centres.
2. *A user-attracting system*, where the facility is located by one agent but the allocation decisions are decentralised and the planner has to make some reasonable guesses as to how the public will make use of the facilities.

In the planning of an air transport network, the location of hubs and the routing of aircraft has to be left under the control of a single decision-maker for proper network planning to ensue. Otherwise, the impact of these decisions on the airline, the passengers and the levels of service/demand would have to be given special consideration. Therefore, for the purposes of this study, the H&S network is designed as a delivery system in which the planning is done by the service provider.

### 5.3.2 Hub airport location

Button et al. (2002) give a quantified definition of airport hubs as entailing carriers feeding three or more banks of traffic daily through an airport from some 40 or more cities. Other definitions of hub airports include having a major carrier at an airport accounting for more than 50% of all local traffic, or having two carriers at an airport together accounting for more than 75% of passenger traffic (Button et al., 2002). There are various factors, pointed out by Schnell and Huschelrath (2004), that influence the likelihood of an airport becoming a hub. Some of these factors are:

- Climatological characteristics of the location
- Geographical location and topographical surroundings
- Market size of the airport
- Inhabitants' income
- Level of development of business and leisure centres to increase the attractiveness of the airport
- Potential of the airport to increase its capacity when there is congestion
- Number of flights operated
- Number of destinations served
- Number of gates available at the airport.

Africa faces the dilemma of not having many international airports with the capacity, demand, market size and infrastructure for hubbing. This is due to the low levels of income in most countries and the expense associated with air travel and its infrastructure. For the purpose of this study, the choice of possible hub airports will be based on the operational effectiveness, in terms of location within the network. The aspects of a hub airport that will not be taken into consideration are the capacity constraints, the slot availability and the state of the infrastructure.

As such, this study provides a first-order assessment of what an optimal or near-optimal H&S network, from an operational cost perspective, would look like. This serves two purposes:

- Firstly, it provides a pointer to and a rationale for the type of H&S network that African airlines and organisations should be moving towards in order to lower costs (even if the exact location of the hubs is open to discussion).
- Secondly, it provides a benchmark against which other alternative network forms and other choices of hub airports (driven by a range of real-life factors such as security, adequate infrastructure and reliable air traffic control systems) can be measured.

### 5.3.3 Node allocation

For an H&S system to be fully effective, there is a need for air passenger systems to locate their hubs with a view to much more than aggregate system travel time (O'Kelly and Bryan, 1998). O'Kelly and Bryan (1999) also emphasise that in order to determine the hub that will result in the lowest travel cost, individual travel costs consisting of three components need to be taken into account:

1. The travel cost from the origin to the hub
2. The cost of travelling across the hub-hub link (if necessary)
3. The travel cost from the hub to the destination.

The passengers from the origin node will connect via the hub airport within the cluster so that they can be routed to their destination nodes. This implies that flow will always go through either one or two hubs, depending on the destination. Direct flights between origin and destination nodes will be allowed only in situations where either the origin or destination node is a hub. This means that the movement in the network falls into the following general categories: node-hub-node (N-H-N); hub-node (H-N); node-hub (N-H); and node-hub-hub-node (N-H-H-N) movement. Each of the nodes is connected to its closest hub and the potential hub airports are fully interconnected. The network design will consider only single-hub allocation because it is easier to implement in the local environment with its operational, political and commercial complexities.

Even though this study channels passengers between two hubs, it has been seen in practice from various hub networks that passengers do not favour this option because it greatly increases their journey time, as stated by Schnell and Huschelrath (2004). In this study, however, this preference of the customers will not be used explicitly as a basis of design, but as an assessment criterion, due to lack of available data.

The allocation of each node to the hub within the cluster based on the findings of the study by O'Kelly and Bryan (1998), namely that the network has an incentive to connect the nodes to hubs as quickly as possible to take advantage of the cheaper hub-hub costs. Therefore, the flow must be deliberately routed to make up economical bundles and the incentives are stacked in favour of large passenger flow.

Competition on each of the routes in the network is neglected because of the lack of available data on competition levels and market share on routes. Furthermore, because of the low passenger demand, there are unequal levels of competition within the African network, with many of the airlines operating as monopolies on certain routes.

### 5.3.4 Network costs

By definition, network costs mean the total costs of transporting passengers from their origin to their destination through the hubs. The costs are calculated as a product of the costs per unit flow and the flow along all the routes. Various network cost equations are given in the literature, but this study is limited to the equations developed for the USAρHMP, using the quadratic optimisation problem with linear constraints of the hub-location problem developed by O'Kelly & Bryan (1998) and rewritten by Klincewicz (1991).

Equation 15, which is used to calculate the network costs, is given as:

$$\mathbf{f(x) = \sum_i \sum_k X_{ik} C_{ik} (O_i + D_i) + \sum_i \sum_k \boldsymbol{X_{ik}} \sum_k \sum_m X_{\boldsymbol{km}} C_{km} W_{k\boldsymbol{m}}} \qquad \textbf{Equation 15}$$

The first term in Equation 15 involves the calculation of the collection and distribution costs (node-hub movement); this part of the equation includes:

- $\mathbf{O_i}$ and $\mathbf{D_i}$ represent the total amount of flow originating and terminating at node i, since all those passengers have to undergo that leg of the journey regardless of their final origin or destination node.
- The factor $\mathbf{X_{ik}}$ is the constraint that addresses the fact that all nodes go through at least one hub. It is represented as 1 if that node-hub movement occurs and as 0 otherwise.
- $\mathbf{C_{ik}}$ represents the cost per passenger from node i to the nearest hub, k.

The second term in Equation 15 calculates the cost of moving the people who are travelling through the hubs k and m:

- The factor $\mathbf{X_{ik}}$ is represented as 1 if that node-hub movement occurs and as 0 otherwise
- The factor $\mathbf{X_{km}}$ is represented as 1 if the hub-hub movement occurs for a given O-D path and as 0 otherwise. This means that only the passenger flow $\mathbf{W_{km}}$ that is determined by the N-H-H-N, H-H-N or H-H movement is included in this part.
- $\mathbf{C_{km}}$ represents the cost per passenger on the H-H links from hub k to hub m. In Klincewicz's Equation 11 in Section 3.7.3, this cost per passenger was reduced by an estimated discount α which represents the discount on fares when a link becomes a H-H link. One of the advantages of using the cost model is that it automatically recalculates the lower cost $\mathbf{C_{km}}$ when a link becomes an H-H link; this eliminates the irregularities that could arise from using an estimated discount α.

### 5.3.5 Application of the cost model to design

The costs per passenger $\mathbf{C_{ik}}$ and $\mathbf{C_{km}}$ used in Equation 15 are derived from the cost model developed by Ssamula (2004)) and described in Chapter 4. The passenger flow to and from each node i and the hub flow $\mathbf{W_{km}}$ are derived from the O-D matrix databases in the cost model. These costs per passenger calculated by the model take into consideration the minimum frequency needed to meet existing demand.

The following assumptions are applicable to the cost model for the design of the various hub networks:

1. The Africa-specific data from the sources stated in the cost model on route distance and passenger data are used for the purposes of this study and are representative of each of the 50 countries.
2. Total flow on a given O-D route is defined by the number of passengers flying both to and from the node.
3. The capital costs included in the operating costs will assume that when the aircraft is not flying, it is to be leased out or used for different routes. Therefore, the capital costs are calculated only as a fraction of the hours the aircraft is being utilised as calculated for the given route.
4. Due to the lack of available data, the O-D matrix has been derived, using the Furness method, from the total passenger demand for flights within Africa, as described in Chapter 4. No long-term forecasts have been used due to lack of demand elasticity values, lack of information on political effects on passenger demand and lack of research on behavioural changes, specific to the African context. This implies that the passenger data are fixed to the base year of 2001 and this is only a first-cut analysis.

## 5.4 Hub-location Strategies

The methods that are used to locate the most cost-effective hubs distinguish the networks from each other. Each network is defined based on the method used for choosing hubs and once the hub location has been determined, the nodes are allocated and the network costs are calculated.

Some of the methods used to choose and evaluate alternative hub locations involve an advanced form of previously used methods of hub location. In this method the network costing involves the costs of operating an airline service to meet the specific demand as passengers are routed via hubs which should lead to an improved result. However, the need to run the cost model repeatedly imposes a methodological constraint as manual manipulation is required to recalculate the flow and costs for each link in the network design. This constraint therefore precludes the use of heuristics or the linear programming approaches that have been used in the literature to identify near-optimal H&S network solutions for networks whose demand and cost elasticity variations are known. A future refinement of the present method could involve the automatic recalculation of costs and this could be applied within a programming environment to find the optimal H&S network for Africa considering a large number of alternatives.

The hub-location strategies that are used in this study to design a cost-effective hub network for the African continent are discussed below. Figure 19 illustrates the procedure that was followed to design the various hub networks using the methods discussed below.

### 5.4.1 One-hub network method

The idea used in this method is that each node can be analysed as a hub option in a one-hub network ($\rho = 1$) of $n = 50$ nodes. Optimising a hub network involves choosing the hubs that will lower the costs of passenger movement. Therefore a $\rho = 1$ hub network is designed, costed and evaluated for each of the 50 nodes within Africa, routing each passenger from origin to destination through this one hub. This approach is not realistic as it requires extremely long, circuitous routes and would therefore not be acceptable in terms of travel time. However, it provides a benchmark against which more complex H&S network options can be measured.

This procedure could be used to find the optimum hub-location choices for the $\rho = 3$ or $\rho = 4$ hub network, but the limitation of using this method is that it is tedious to run manually. For example for the $\rho = 5$ network, the cost model would have to be run 2 118 760 times to evaluate all possible options in order for the optimum hub-location choices to be attained. As an alternative for the vast African network of 50 nodes, the clustering method used in the literature is recommended, so that the network is divided into smaller clusters.

### 5.4.2 Clustering method

The method of clustering involves dividing large networks into clusters, where each cluster comprises the nodes within that specific area. This method narrows down the hub-location search from all the nodes in a large network to only a few nodes in each cluster. Each cluster is then analysed as a $\rho = 1$ network to locate the most probable hub using a defined set of rules. The cluster method will be used to investigate:

1. The optimum number of hubs for the African network.
2. The optimum location of hubs in clusters using the following methods:
    a. The Klincewicz method of hub location described in Section 3.6.4, in which the probability of a node becoming a likely hub in a cluster is based on shortest distances and high passenger numbers.
    b. The modified Klincewicz clustering method, in which the probability of a node becoming a likely hub in a cluster is based on its operating costs, derived from the cost model.

**HUB LOCATION**
Hubs are located using the methods outlined below.

**Node-hub analysis:**

- Four nodes with the cheapest total cost per passenger of transferring passengers originating from each node to their respective destinations.
- Four nodes with the cheapest total cost per aircraft-km of transferring passengers originating from each node to their respective destinations.

**Clustering method:**
If Africa was to be divided into clusters:
How many clusters would make an optimum network?

Indexes are awarded for the most probable hub in the cluster in terms of:

- shortest distance to get to or from the other nodes in the cluster
- highest passenger numbers flowing from all the other nodes within the cluster
- highest total ratio of distance to passengers

Indexes are awarded for the most probable hub in the cluster in terms of:

- lowest cost per passenger to transmit flow to the other nodes in the cluster

**One-hub network method:**
If Africa was to have a one-hub network, which would be the four cheapest hub networks to fly?

**Geo-political method:**
The four airports with the highest demand and capacity, and most strategically situated in the **north, south, east** and **west** regions of Africa.

**NODE ALLOCATION**
Nodes are allocated to the nearest single hub using the closest hub method.

**NETWORK COST**
Modified Klincewicz (1991) USAρHMP equation:

$$\mathbf{f\,(x) = \sum_i \sum_k X_{ik}\, C_{ik}\, (O_i + D_i) + \sum_i \sum_k \mathit{X_{ik}} \sum_j \sum_m X_{jm} C_{jm}\, W_{jm}}$$

**Figure 19: Network design process flow chart**

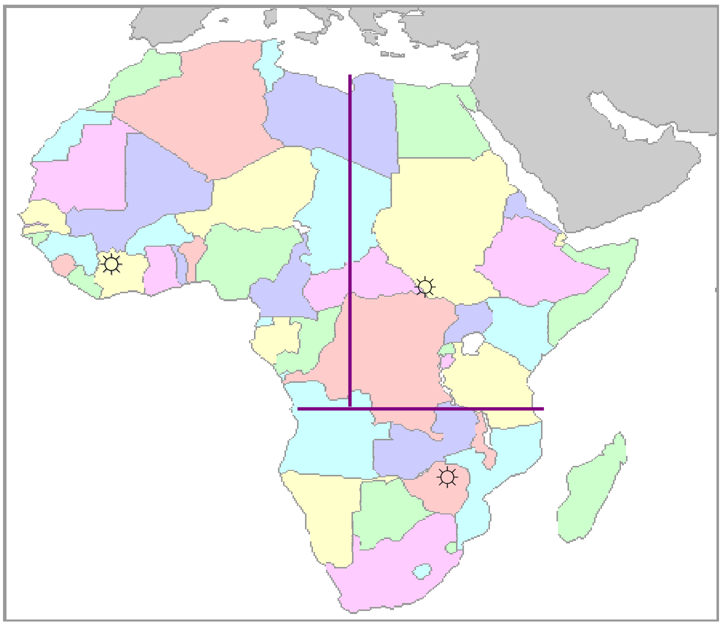
#### 5.4.2.1 Optimum number of hubs

In their study, O'Kelly and Bryan (1998) state that as flow increases on Hub-hub links, the cost per unit flow on the same link will decrease. The uncertainty with the African continent lies in ascertaining how many hubs would be optimal for the continent?

A procedure was performed by Topcuoglu et al. (2005) to test for the cost benefits of locating a hub as centrally as possible within a cluster. It involved finding the geographical location of the mid-point using the latitude and longitude of all nodes in the cluster and then choosing the node that was nearest to the mid-point to act as a hub. This method was applied to the African continent to find the optimum number of hubs for a hub network by testing two-, three-, four- and five-cluster networks using the following procedure:

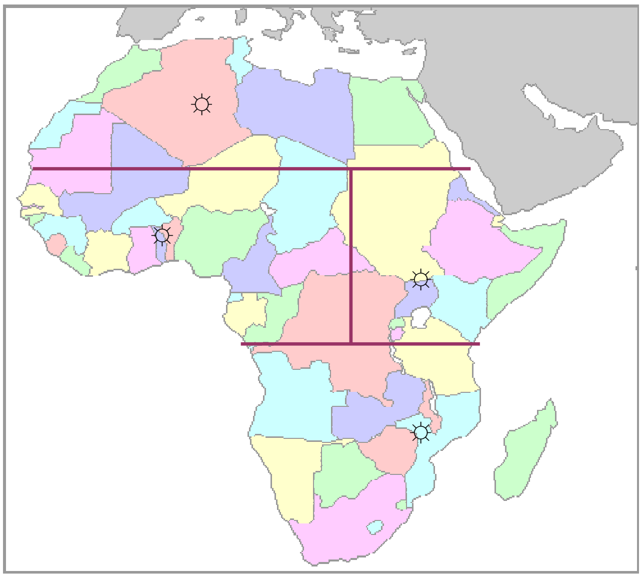
1. List the geographical position of all the airports within the network, i.e. the latitudes and longitudes.
2. Divide the African continent into clusters, for $\rho = 3$, $\rho = 4$ or $\rho = 5$ hub networks. The demarcation of the cluster boundaries is done on the basis of Regional Economic Communities (RECs). Using RECs offers an advantage because member countries have already established trust through regional trade agreements. Figure 20, Figure 21 and Figure 22 show the cluster divisions, the RECs in that geographical region, and the virtual hub locations for the three-, four- and five-cluster networks respectively.
3. Take the mid-point of each of these clusters, using the latitude and longitude, as the virtual hub airport location for the cluster.
4. Allocate the flow from each node through the hub to its final destination, including the flow between clusters.
5. Calculate the cost of the $\rho = 3$, $\rho = 4$ or $\rho = 5$ hub networks.

Once the optimum number of hubs has been found for the African region, a more logical procedure that lowers the hub network costs is used to locate the most probable hubs, using their exact locations.



1. West (ECOWAS & UMA)
   Mid-point: 12.54 N 5.58W
2. East: (COMESA &UMA)
   Mid-point: 10.32N 24.25E
3. South (SADC)
   Mid-point: 15.84S 30.14E

**Figure 20: Three-cluster network**



1. West (ECOWAS)

   Mid-point: 8.14 N 2.74W

2. East (EAC)

   Mid-point: 2.74N 31.40E

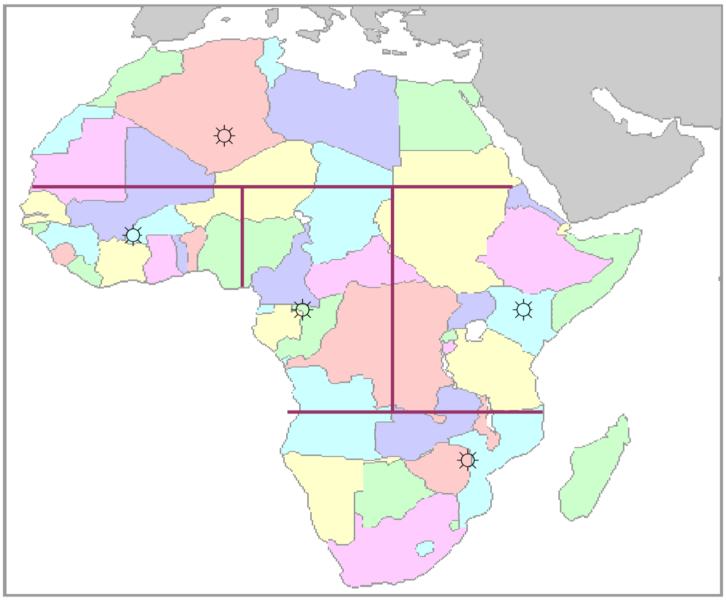
3. South ( SADC)

   Mid-point: 21.25S 31.21E

4. North (UMA)

   Mid-point: 27,15N 3.65E

**Figure 21: Four-cluster network**



1. West (ECOWAS)

   Mid-point: 9.876 16W

2. East(EAC)

   Mid-point: 3.99N 36.40E

3. South(SADC)

   Mid-point: 22.48S 33.01E

4. Central Economic and Monetary Community of Central Africa (CEMAC)

   Mid-point: 0.82N 12.65E

5. North (UMA)

   Mid-point: 29.30N 2.02E

**Figure 22: Five-cluster network**

#### 5.4.2.2 Klincewicz's clustering method

This process aims at finding the most probable hub within a cluster, either because it has the shortest total N-H distances or because it has the highest passenger demand. In the calculation of indexes for each node, the highest index of 1 is awarded to the node with the shortest distance and highest number of passengers flying to it. An example of the procedure for calculating the indexes is illustrated in Table 11, Table 12 and Table 13 for a northern cluster in a five-cluster network. Table 11 shows the O-D matrix, with the maximum passenger flow in bold for all the O-D pairs in each row. The O-D matrix was derived using Furness' method in the cost model and is approximately symmetrical.

**Table 11: Passenger flow within a cluster**

| Flow | ALG | CAI | FEZ | NDJ | NKC | SID | TIP | TUN |
|---|---|---|---|---|---|---|---|---|
| **ALG** | 0 | 140 047 | **206 009** | 5 651 | 6 965 | 27 959 | 21 992 | 81 810 |
| **CAI** | **140 043** | 0 | 129 114 | 5 383 | 4 664 | 18 380 | 17 966 | 60 323 |
| **FEZ** | **206 010** | 129 118 | 0 | 5 626 | 7 869 | 31 827 | 20 435 | 74 816 |
| **NDJ** | **5 651** | 5 383 | 5 626 | 0 | 244 | 960 | 699 | 2 294 |
| **NKC** | 6 965 | 4 665 | **7 869** | 244 | 0 | 1 844 | 726 | 2 566 |
| **SID** | 27 959 | 18 381 | **31 828** | 960 | 1 844 | 0 | 2 873 | 10 237 |
| **TIP** | **21 992** | 17 966 | 20 435 | 699 | 726 | 2 873 | 0 | 9 297 |
| **TUN** | **81 809** | 60 325 | 74 815 | 2 294 | 2 566 | 10 237 | 9 297 | 0 |

Table 12 shows the procedure for awarding indexes; an index of 1 is awarded to the destination node with the highest number of passengers from each of the origin nodes. The indexes for the rest of the nodes in the row are calculated in proportion to the maximum passenger flow. In the first row we can see that ALG-FEZ has an index of 1 because it has the highest flow from ALG. The index for ALG-CAI is calculated as follows: $\frac{140047}{206009} = 0.680$

**Table 12: Flow index calculation for each O-D pair**

| Indexes | ALG | CAI | FEZ | NDJ | NKC | SID | TIP | TUN |
|---|---|---|---|---|---|---|---|---|
| **ALG** | | 0.680 | 1.000 | 0.027 | 0.034 | 0.136 | 0.107 | 0.397 |
| **CAI** | 1.000 | | 0.922 | 0.038 | 0.033 | 0.131 | 0.128 | 0.431 |
| **FEZ** | 1.000 | 0.627 | | 0.027 | 0.038 | 0.154 | 0.099 | 0.363 |
| **NDJ** | 1.000 | 0.953 | 0.996 | | 0.043 | 0.170 | 0.124 | 0.406 |
| **NKC** | 0.885 | 0.593 | 1.000 | 0.031 | | 0.234 | 0.092 | 0.326 |
| **SID** | 0.878 | 0.578 | 1.000 | 0.030 | 0.058 | | 0.090 | 0.322 |
| **TIP** | 1.000 | 0.817 | 0.929 | 0.032 | 0.033 | 0.131 | | 0.423 |
| **TUN** | 1.000 | 0.737 | 0.915 | 0.028 | 0.031 | 0.125 | 0.114 | |
| | **6.764** | **4.984** | **6.761** | **0.214** | **0.271** | **1.081** | **0.754** | **2.667** |

Indexes are calculated for each row and the sums of the indexes are given in the bottom row of Table 12. These sums show that the most probable hub option in this cluster, in terms of flow, is ALG which has the highest index of 6.764. This process is repeated for the distance matrix for this cluster, choosing the node with the shortest distance as the one with the highest index.

The passenger and flow indexes are summarised in Table 13 and again show that the most probable hub in this cluster, in terms of passenger flow, is ALG with an index of 6.764, while the most probable airport in terms of distance is NDJ with an index of 4.676. The total indexes are calculated to show that the most probable hub in terms of highest passenger numbers and shortest distance is ALG with an index of 10.005. This method assumes that the shortest distance and the highest passenger numbers contribute equally to making a node a suitable hub.

**Table 13: Total index calculation for distance and passengers in a cluster**

| Node | Flow | Dist | Total |
|---|---|---|---|
| ALG | 6.764 | 3.241 | 10.005 |
| FEZ | 6.761 | 2.229 | 8.990 |
| CAI | 4.984 | 3.677 | 8.661 |
| NDJ | 0.214 | 4.676 | 4.890 |
| TUN | 2.667 | 2.133 | 4.800 |
| SID | 1.081 | 1.986 | 3.068 |
| TIP | 0.754 | 2.154 | 2.908 |
| NKC | 0.271 | 2.200 | 2.471 |

This procedure is carried out for the distance and O-D matrices for each cluster for all the ρ =3, 4 and 5 networks. Thereafter the hubs from the separate clusters are chosen and the networks are costed.

#### 5.4.2.3 Modified clustering heuristics

This method modifies Klincewicz's clustering heuristics method by changing the criteria for choosing the node, from that with the highest index on the basis of shortest distances and highest passenger numbers, to that with the lowest node-hub costs in the cluster. The cost model developed by Ssamula (2004), which calculates the operating costs of an airline service on a given route, is used to derive the node-hub costs. The matrices developed in this method calculate indexes based on the costs per passenger in US$ for each O-D pair within the cluster. The rationale behind this process is that the cost model calculates the operating costs for each node-hub movement in the cluster such that the most attractive node within the cluster to be chosen as a hub has the lowest total operating costs for movement of flow. This method ends up doing directly what Klincewicz's method tries to do by approximation.

The process used to calculate the indexes for each O-D pair is similar to Klincewicz's method, with the highest index of 1 being awarded to the pair that has the lowest costs per passenger. The node with the highest index, summed overall on all the links, is chosen as the hub in the cluster. The index calculation of the cost per passenger for the northern cluster is shown in Table 14. The most probable hub airport in this cluster, with the lowest total costs per passenger, is CAI with an index of 6.388.

**Table 14: Total index calculation for costs within a cluster**

| | Costs per passenger index |
|---|---|
| ALG | 4.072 |
| CAI | 6.388 |
| FEZ | 3.496 |
| NDJ | 3.749 |
| NKC | 4.687 |
| SID | 3.185 |
| TIP | 5.128 |
| TUN | 4.192 |

This procedure is carried out for each cluster for all the ρ = 3, 4 and 5 networks and after the hubs from the separate clusters have been chosen, the networks are costed. The advantage of this modification is that it gives the most favourable hub choices, in terms of the costs of moving actual passengers along route distances in these clusters. The rationale for using the two different hub-location methods is to investigate whether using basic route parameters, such as the distance and passenger numbers shown in Klincewicz's method, has a greater effect on lowering network costs than using the lowest calculated operating costs.

### 5.4.3 Node-hub analysis

The node-hub links in any hub network contribute more to network costs than the hub-hub links (O'Kelly and Bryan, 1998). This is because the hub-hub links benefit more from the economies of scale gained from consolidated flow. This implies that since the node-hub portion of the journey is more costly, a strategy aimed at minimising the costs on the node-hub link needs to be explored. The aim of the strategy is to lower the cost of transporting passengers either to or from the hub chosen on the node-hub link in an H&S network.

The costs per passenger and costs per aircraft-km, on each O-D link in the 50-by-50 matrix, are calculated using the cost model. Thereafter the nodes that have the cheapest total costs are used as hub-location options.

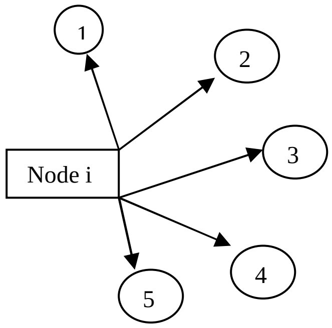



Figure 23 represents the cost of transporting flow "from" each node ($O_i$). The total cost from node i to each of the n nodes in the network is summed. The nodes that have the cheapest costs of transporting flow from them are used as hub-location options.

$$O_i = \sum_{1}^{50} C_{i-n} = C_{i-1} + C_{i-2} + \ldots . + C_{i-n} + C_{i-50}$$

**Figure 23: The cheapest hub to fly "from"**

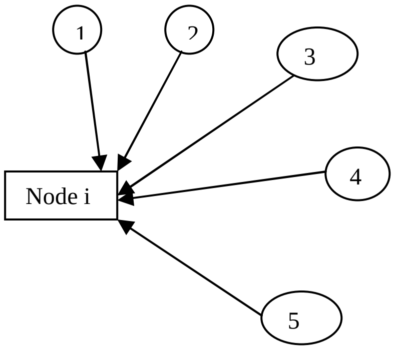



Figure 24 illustrates the calculation of the cost of transporting flow "to" each node ($D_i$). The total costs for all the nodes in the network are summed. The nodes that have the lowest costs to fly to as destinations are used as hub-location options.

$$D_i = \sum_{1}^{50} C_{n-i} = C_{1-i} + C_{2-i} .. + C_{n-i} + C_{50-i}$$

**Figure 24: The cheapest hub to fly "to"**

The hub-location method is used to analyse the African air network by choosing the nodes that have the lowest cost of transporting flow. The characteristics that would lower the costs of transporting flow include geographical location, passenger demand and sector distances.

### 5.4.4 Geo-political method

The aviation industry in Africa is still a very politically governed industry with most airlines being used as flag carriers. Despite government involvement, most airports still lack proper infrastructure and are not running profitably. Therefore this geo-political method will assess the airports that are well established, both politically and geographically, and give reasons as to why they are suitable hub choices. After these hubs have been chosen, the nodes are allocated and the network is costed. The general characteristics taken into consideration for choosing airports as suitable hubs include the following:

1. The presence of high passenger demand at an airport implies that the airport is already a popular destination. The economies of scale enjoyed on routes to and from these busy airports would mean lower transportation costs on the node-hub links.
2. The presence of adequate infrastructure in terms of runways, gates and aprons to accommodate a high frequency of flights is vital. This would mean that minimum additional investment would be needed when converting airports to hubs.
3. The hub airport should be conveniently located geographically, so that it is well connected as a hub and does not inconvenience passengers.
4. The hub airport should be near the economic heart of the region so that it is able to nurture economic growth through employment, infrastructure and development. Button et al. (2006) state that an areas attracts foreign investment through having good transportation services available and he cites Heathrow airport in the UK and Washington's Dulles International airport in the US as examples.

The continent was divided into four geographical regions, based on the optimum number of hubs derived in Section 5.3.2. These geographical divisions are also aligned with the existing Regional Economic Communities (RECs) though which trade agreements and economic cooperation have already been established, creating trust among member countries. The RECs listed in their specific regions are:

1. United Maghreb Union (UMA) in the north
2. East African Community (EAC) or Common Market for Eastern Southern Africa (COMESA) in the east
3. Economic Community for West African States (ECOWAS) in the west
4. Southern African Development Community (SADC) in the south.

All the international airports used in the database of the cost model were analysed using data from various aviation authorities, as shown in Table 15. Special consideration was given to airports that are currently being used as hubs in these regions. The parameters used to justify potential hub airport options for each cluster include:

- **Passenger demand.** High passenger demand reflects the infrastructure capacity of the airport and economies-of-scale benefits on the node-hub links.
- **Number of runways.** These determine the infrastructure handling capacity for the high passenger demand levels expected at hub airports.
- **Number of airlines operating.** This reflects the airport's operational capacity in terms of gates, slots, baggage-handling processes and aircraft turnaround time.

- **Airport hub capabilities or functionality.** This implies that since an airport is already being used as a connection point at geographical or airline level, the transition to becoming a hub would be facilitated.
- **Node-hub distances.** If the distances on the node-hub link can be minimised, the operating costs will be lower. Nodes within a cluster will then be assigned to the potential hub airport, ensuring that a maximum distance of 3 500 km is maintained. This will encourage the use of smaller, cheaper short-range aircraft, which will minimise costs.

**Table 15: Criteria for choosing the most likely hubs**

| **Item** | **North** | | | **South** | **East** | | **West** | |
|---|---|---|---|---|---|---|---|---|
| **Candidate airport** | **FEZ** | **ALG** | **CAI** | **JNB** | **NBO** | **ADD** | **KAN** | **DKR** |
| **Country** | **Morocco** | **Algeria** | **Egypt** | **South Africa** | **Kenya** | **Ethiopia** | **Nigeria** | **Senegal** |
| Passenger numbers | 1 329 040 | 1 329 036 | 1 242 000 | 3 669 000 | 741 000 | 843 000 | 252 000 | 19 500 |
| Node-hub distances | 13 642 | 15 069 | 31 134 | 11 114 | 10 360 | 10 762 | 33 775 | 53093 |
| Airlines served | 16 | 14 | 49 | 42 | 45 | 19 | 36 | 28 |
| Number of runways | 1 | 2 | 3 | 3 | 2 | 1 | 2 | 2 |
| Major function | Europe-Africa link | Europe-Africa link | Egypt Air hub | SAA hub, Trans-Atlantic link | Transit hub, regional hub | Airline hub | Regional hub | Re-fuelling hub |
| **Hub choice** | **FEZ** | | | **JNB** | **NBO** | | **KAN** | |

In the north, Egypt is eliminated due to the fact that it has very long node-hub distances, even though it has high passenger numbers. Instead, FEZ in Morocco is chosen because it has shortest node-hub distances and at present has more airlines serving the airport.

In southern Africa, South Africa currently acts as a hub from Asia to Africa, is a hub to a major airline carrier in the region (South African Airways), and is suitably located within the southern portion of the continent.

In East Africa, the two probable hubs are found in Ethiopia and Kenya. Even though ADD has higher passenger numbers, it has higher total node-hub distances for all nodes. NBO in Kenya, on the other hand, is chosen because it serves more airlines and has greater runway capacity, as its acts as a major connection hub for larger carriers such as Kenya Airways and KLM.

In West Africa, Nigeria has higher passenger capacity, shorter node-hub distances within the region, serves more airlines, and is more suitably located in the western portion of the continent. Figure 25 shows the geographical boundaries of the geo-political network chosen.

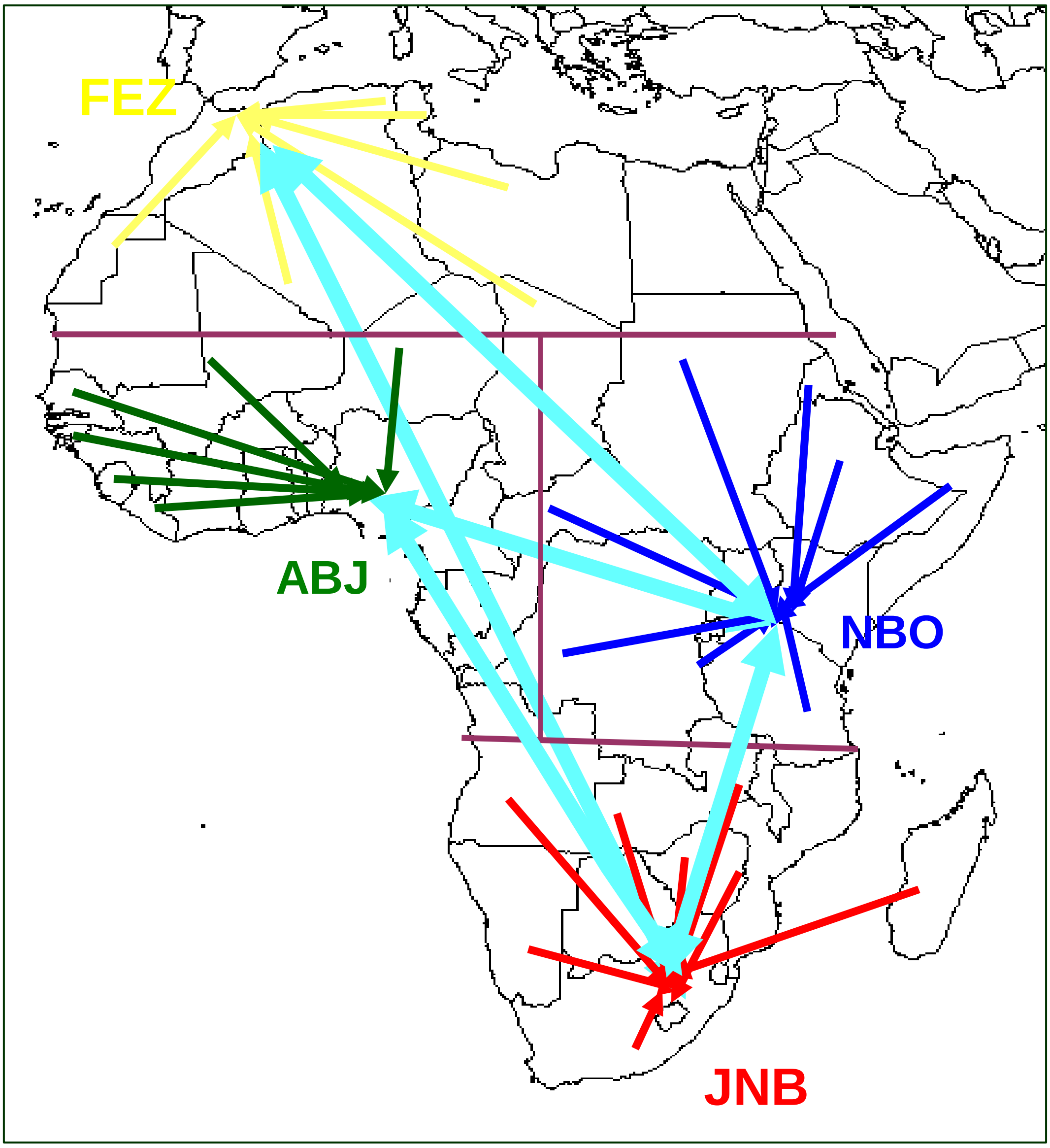



**Figure 25: Geo-political network**

# CHAPTER 6: RESULTS AND ANALYSIS

## 6.1 Introduction

This chapter gives the results and analyses of the various hub networks that have been designed using the methods described in Chapter 4. The sensitivity of the hub-design process to the network costs is also investigated. The calculation of discounts on inter-hub links specific to the African network is carried out. Table 16 summarises the hub-and-spoke (H&S) network costs, which have been split into node-hub, hub-hub and total network costs. Even though the cheapest network is the one-hub network, it would not be practical to have one hub on such a vast continent. The cheapest practical network was found to be the geo-political network (highlighted in the table). The percentage variation from the cheapest practical network is shown in the second-last column. The last column, which is headed ‘Total passenger travel time expenditure’, shows the travel time for all passengers from their origins to their destinations. This analysis is aimed at inferring how the design parameters, which include hub location, distances and passenger numbers, affect movement and the time costs for each H&S network.

**Table 16: Summary of different hub network costs**

| No | Network Types | Hub airport locations | Node-hub costs (US$) | Hub-hub costs (US$) | Total costs (US$) | % diff. from Network 2 | Total pass. travel time expenditure (pass-h) |
|---|---|---|---|---|---|---|---|
| 1 | Geo-political | .FEZ-JNB-NBO-.KAN | 851 005 541 | 724 350 402 | 1 575 355 943 | 0.00% | 112 084 885 |
| 2 | One-hub network | .TMS | 1 521 300 419 | 0 | 1 521 300 419 | -3,43% | 141 732 732 |
| 3 | Clusters 2 | .Mid-points | 2 808 954 950 | 470 214 725 | 3 279 169 675 | 108% | 149 495 864 |
| 4 | Clusters 3 | .Mid-points | 2 129 156 696 | 637 616 805 | 2 766 773 501 | 75.63% | 117 869 225 |
| 4 | Clusters 4 | .Mid-points | 1 049 102 631 | 867 861 904 | 1 916 964 535 | 21.68% | 120 77 306 |
| 6 | Clusters 5 | .Mid-points | 977 704 093 | 985 471 002 | 1 963 175 095 | 24.62% | 108 523 760 |
| | **NODE-HUB ANALYSIS** | | | | | | |
| 7 | Cost per pass. to | .NSI-COO-LFW-.TMS | 1 392 565 207 | 374 486 912 | 1 767 052 119 | 12.17% | 140 149 429 |
| 8 | Cost per pass. from | .CAI-JNB-NBO | 1 108 638 521 | 814 978 654 | 1 923 617 175 | 22.11% | 136 166 180 |
| 9 | Cost per aircraft-km to | .BGF-OUA | 1 307 703 384 | 390 629 014 | 1 698 332 398 | 7.81% | 129 773 048 |
| 10 | Cost per aircraft-km from | .ALG-JNB-ADD-.CAI | 969 263 227 | 1 022 110 456 | 1 991 373 683 | 26.41% | 130 754 893 |
| | **CLUSTERS 5** | | | | | | |
| 11 | Klincewicz’s method | .ALG-LBV-KAN-.ADD-JNB | 814 102 323 | 1 060 831 867 | 1 874 934 184 | 19.02% | 111 331 865 |
| 12 | Modified Klincewicz’s method | .ALG-JNB-ADD-.ABJ-FIH | 770 627 166 | 1 076 267 842 | 1 846 895 008 | 17.24% | 92 838 440 |
| | **CLUSTERS 4** | | | | | | |
| 13 | Klincewicz’s method | .ALG-JNB-ADD-.KAN | 859 974 307 | 992 701 815 | 1 852 676 122 | 17.60% | 115 690 086 |
| 14 | Modified Klincewicz’s method | .CAI-JNB-ADD-.ABJ | 833 740 441 | 1 023 900 295 | 1 857 640 736 | 17.92% | 96 344 797 |
| | **CLUSTERS 3** | | | | | - | |
| 15 | Klincewicz’s method | .KGL-JNB-BJL | 1 067 998 046 | 822 383 914 | 1 890 381 960 | 20.00% | 140 508 228 |
| 16 | Modified Klincewicz’s method | .JNB-ADD-FEZ | 1 022 158 662 | 927 117 792 | 1 949 276 454 | 23.74% | 107 761 707 |

## 6.2 One-hub Network Analysis

**Table 17: One-hub network costs**

| No. | Network type | Hub airport location | Node-hub costs (US$) | Hub-hub costs (US$) | Total costs (US$) | % diff. from Network 1 | Total pass. travel time expenditure (pass-h) |
|---|---|---|---|---|---|---|---|
| 1 | Geo-political | FEZ-JNB-NBO-KAN | 851 005 541 | 724 350 402 | 1 575 355 943 | 0,00% | 112 084 885 |
| 2 | One-hub network | TMS | 1 521 300 419 | 0 | 1 521 300 419 | -3,43% | 141 732 732 |

It is seen from the one-hub network costs shown in Table 17 that the cheapest hub node, TMS, is located centrally in Africa in Sao Tome & Principe. The shortest sector distance for this node is 300 km, while the farthest node is 6 002 km and the average sector distance is 2 710 km. Since 53% of the links are less than 3 000 km long, cheaper, shorter-range aircraft can be used for these links, making this network cheap. This network has only node-hub links because there is only one hub. However, even though it is the most efficient network, it would be impractical to fly passengers through one central hub, especially if the direct O-D link has a shorter distance that the node-hub-node link option given in this network. The passenger travel time expenditure would be 26% higher than with the geo-political network. The extra travel time posed by this network design is an inconvenience to the passengers, putting the design at a disadvantage.

## 6.3 Geo-political Method

**Table 18: Geo-political hub network costs**

| No. | Network type | Hub airport locations | Node-hub costs (US$) | Hub-hub costs (US$) | Total costs (US$) | % diff. from Network 1 | Total pass. travel time expenditure (h) |
|---|---|---|---|---|---|---|---|
| 1 | Geo-political | FEZ-JNB-NBO-KAN | 851 005 541 | 724 350 402 | 1 575 355 943 | 0,00% | 112 084 885 |

Apart from the one-hub option, the geo-political network shown in Table 18 has the lowest network costs compared with all the network designs described in Chapter 5. At present the hub airports JNB, FEZ and NBO are all being used as hubs by the local national airlines to connect passengers to other airports. Some of the reasons for the lowest costs are that the hub airports chosen are all centrally located within their geographical boundaries of north, south, east and west. The hub options also have high passenger demand, which means that economies of scale are enjoyed on the node-hub link. Moreover, they have the advantage of possessing infrastructure that can handle large traffic flow which is a common characteristic of hub airports. Furthermore, the total passenger travel time expenditure in this network is among the lowest, making it a convenient route network for passengers. This shows that cheap options for hubs can be those airports that are located centrally within a region and have high passenger demand.

## 6.4 Clustered Hub Network Analysis

In this section, the networks that have been designed using clusters in large geographical regions are costed and analysed. Firstly, the application of clustering to find the optimum number of hubs in the African network is discussed. Thereafter the hub networks, whose methods of hub location are based on the clustering methods described in Section 5.4.2, are costed and analysed.

### 6.4.1 Optimum number of clusters

In order to find the optimum number of hubs for the network, virtual hubs are found at the centre of each cluster for a two-, three-, four- and five-cluster network. This systematic method is then used to analyse the effect on costs of increasing the number of hubs. It should be expected that as the number of hubs increases, the total network costs decrease. This is because fewer hub links would have a higher passenger density and thus enjoy better economies of scale.

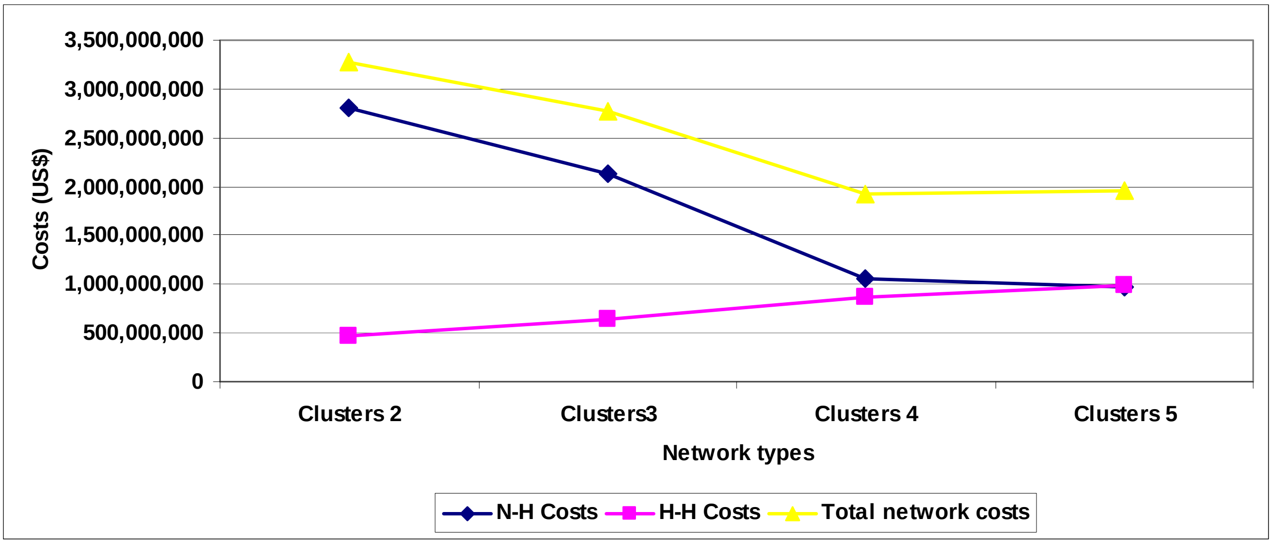



**Figure 26: Cost variations as clusters increase in a network**

Figure 26 illustrates the costs of the network for the two-, three-, four- and five-cluster network. A number of trends are observed and these will now be discussed. The hub-hub costs are generally lower than the node-hub costs in the networks due to the better economies of scale enjoyed on inter-hub links. The hub-hub costs increase as the number of clusters in a network increases. This is because the number of hub-hub links in the network increases from 1–3 to 6–10 for a two-, three-, four- and five-cluster network respectively. Fewer hub-hub links mean higher passenger densities, hence better economies of scale, thus lowering the hub-hub costs for the network. The trend for node-hub costs first decreases from the three- to four-cluster networks and then seems to increase for the five-cluster network. Table 19, which shows the general characteristics of links within clusters, will help to explain this trend.

**Table 19: Characteristics of node-hub links in the various cluster networks**

| Network | Average N-H distance (km) | Costs per passenger (US$) x No. of clusters | Average annual passenger demand in the clusters |
|---|---|---|---|
| 2-cluster network | 2 043 | 130*2 | 8 253 842 |
| 3-cluster network | 1 572 | 106 *3 | 5 545 376 |
| 4-cluster network | 1 282 | 102 *4 | 4 159 032 |
| 5-cluster network | 1 052 | 91*5 | 3 327 225 |

As the number of clusters in a network increase, the size of the clusters is expected to decrease. Therefore, as cluster size decreases, the passenger demand in each cluster reduces. Furthermore, the average for the node-hub link will decrease as the number of clusters increases. The shorter distances should reduce the costs per unit flow as clusters increase, but the passenger demand is also decreasing. Therefore the decreasing passenger demand in the clusters reduces economies of scale, such that the five-cluster network has the highest node-hub costs.

Based on the total network costs, it appears that the optimum network for the continent would be either a four-hub network or a three-hub network, because they have the lowest costs.

### 6.4.2 Clustering heuristics network

This section discusses the two results of the clustering hub-location methods. The hub-location methods are:

- The Klincewicz (1991) method of locating the most probable hub as the node with the highest index total in terms of both distance and passengers
- The modified Klincewicz method of using the most probable hub as the node with the total cheapest cost per passenger of transporting flow derived by means of the cost model.

Table 20 shows the network costs derived from the two methods, after which the results are analysed.

**Table 20: Clustering operating costs**

| No. | Network types | Hub airport locations | Node-hub costs (US$) | Hub-hub costs (US$) | Total costs (US$) | % diff. from network 2 | Total pass. travel time expenditure |
|---|---|---|---|---|---|---|---|
| | **CLUSTERS 5** | | | | | | |
| 11 | Klincewicz's method | ALG-LBV-KAN-ADD-JNB | 814 102 323 | 1 060 831 867 | 1 874 934 184 | 19.02% | 111 331 865 |
| 12 | Modified method | CAI-JNB-ADD-ABJ-FIH | 770 627 166 | 1 076 267 842 | 1 846 895 008 | 17.23% | 92 838 440 |
| | **CLUSTERS 4** | | | | | | |
| 13 | Klincewicz's method | ALG-JNB-ADD-KAN | 859 974 307 | 992 701 | 1 852 676 122 | 17.60% | 115 690 086 |
| 14 | Modified method | ALG-JNB-ADD-ABJ | 833 740 441 | 1 023 900 | 1 857 640 736 | 18.58% | 96 344 796 |
| | **CLUSTERS 3** | | | | | | |
| 15 | Klincewicz's method | KGL-JNB-BJL | 1 067 998 046 | 822 383 | 1 890 381 960 | 20.00% | 140 508 228 |
| 16 | Modified method | JNB-ADD-FEZ | 1 022 158 662 | 927 117 | 1 949 276 454 | 23.74% | 107 761 707 |

The trends shown in Section 6.4.1 are reaffirmed in this section. The node-hub costs increase with a decrease in the number of clusters in a network, while the hub-hub costs decrease as the number of clusters in a network decreases. Once again, the four-cluster network turns out to be the network with the cheapest costs for the region.

The total passenger travel time expenditure decreases with an increase in the number of clusters in a network. This can also be explained by Table 19, which shows that with more clusters in the network, the cluster sizes reduces, lowering travel distances and thus shortening passenger travel time.

Once more the airports that have high passenger numbers, such as ALG, JNB and ADD, are constantly chosen as hubs in their clusters irrespective of the hub-location method used and the number of clusters. The nodes characterised by high passenger demand are already attractive in terms of distances and passenger numbers and thus have lower node-hub costs.

The modified method of using cost-per-passenger indexes results in cheaper node-hub costs than does Klincewicz's method. This is because the modified method favours hubs that have the cheapest calculated costs of transporting flow within the cluster. This could also be the reason for the modified method having lower passenger travel time expenditure, as seen with the geo-political network.

The hub-hub costs for the modified method are more expensive than for Klincewicz's method. This implies that Klincewicz's method, in which the emphasis is placed on the strategic location of the hub, leads to a reduction in hub-hub costs. The next question then would be to try to ascertain whether distance and passenger numbers have equal effects on reducing the cost of a network.

A percentage analysis of costs carried out for all the networks calculated shows that, on average, the node-hub costs contribute about 58% of the total costs, while the hub-hub costs cover only 42% of the network costs. This confirms O'Kelly and Bryan's (1998) findings that the hub-hub portion of the trip costs less than the spoke portion. Therefore, a network has an incentive to connect the nodes to the hubs as quickly as possible to take advantage of the cheaper hub-hub costs.

## 6.5 Node-hub Network Analysis

The basis for the design of the H&S networks in Table 21 is an attempt to minimise the node-hub costs using the results from the cost model. The hub-location options for the different networks are chosen based on the operating costs of supplying the service at the existing level of passenger demand.

**Table 21: Results of the node-hub network analysis**

| No. | Network type | Hub airport locations | Node-hub costs (US$) | Hub-hub costs (US$) | Total costs (US$) | % diff. from Network 1 | Total pass. travel time expenditure |
|---|---|---|---|---|---|---|---|
| 7 | Cost per passenger 'to | NSI-COO-LFW-TMS | 1 392 565 207 | 374 486 912 | 1 767 052 119 | 12.17% | 140 149 429 |
| 8 | Cost per passenger from | CAI-JNB-NBO | 1 108 638 521 | 814 978 654 | 1 923 617 175 | 22.11% | 136 166 180 |
| 9 | Cost per aircraft-km to | BGF-OUA | 1 307 703 384 | 390 629 014 | 1 698 332 398 | 7.81% | 129 773 048 |
| 10 | Cost per aircraft-km from | ALG-JNB-ADD-CAI | 969 263 227 | 1 022 110 456 | 1 991 373 683 | 26.41% | 130 754 893 |

### 6.5.1 Cost per passenger demand

The design of Network 7 is based on using the cheapest nodes *to which* to fly the passengers as hub options. The network has its hub locations at NSI, COO, LFW and TMS, all of which are located in countries centrally within Africa. This network has short node-hub and hub-hub distances and that is why the network costs are low. The strategic location of the hubs results in a network that is only 12,17% higher in cost than the most efficient network. The network costs are low despite the fact that the passenger demand originating from these nodes is not high.

The design of Network 8 is based on using the cheapest nodes *from which* to fly the passengers as hub options. The hubs chosen coincidentally have the highest passenger demand within the region. The high passenger demand lowers the node-hub costs because the aircraft fly at high load factors.

### 6.5.2 Costs of service supply

Network 9 is an H&S network having the airports with the lowest cost of supplying a service as hub options. This network originally had four hubs, but they had short inter-hub distances – as short as 40 km – so the hub choices were reduced to two hubs. BGF and OUA are located centrally within Africa and have low passenger demand. This is the cheapest of the node-hub networks, and its cost is higher than the lowest network by only 7,81%. This is due to the short node-hub distances, only one inter-hub link that would have a high passenger density, and lastly the short inter-hub distances at 2 371 km. This network proves that point that centrally located hubs, even with short distances, increase passenger travel time by 15% over the lowest geo-political network with four hubs.

Network 10 has hub-location choices that are based on the airports with high passenger demand. This makes them the four cheapest airports to fly from in terms of aircraft-km. This is because as passenger numbers increase, the operating costs are spread out amongst the passengers as flight frequencies and fleet size increase.

The conclusion for the node-hub analysis is that hubs with higher passenger demand have cheaper node-hub costs due to economies of scale. Having hubs with short inter-hub links lowers hub costs because operating costs increase as route distances increase. The strategic location of the hubs (For example Network 7 which is 12,17% more expensive than the geo-political network) can outweigh the economies of scale achieved through high traffic volumes (For example Networks 8 and 10 which are respectively 22,11% and 26,41% more expensive than the cheapest network).

## 6.6 Sensitivity Analysis of the Network Design Process

Sensitivity analysis is carried out to test the process used for network design. The design inputs are subject to many sources of uncertainty, including errors of measurement, absence of information and poor or only partial understanding of the driving forces and mechanisms. The sensitivity analysis in this study can be used to determine:

- Factors that contribute the most to the output variability
- Interactions between factors.

### 6.6.1 Procedure

The sensitivity analysis will be carried out for the geo-political network in which the boundaries for geographical position were chosen on the basis of Regional Economic Communities (RECs). The adjusted network involves redrawing the boundaries of the geo-political network such that each node is assigned to its closest hub. This network will then be costed to test the effect of this adjustment on the network costs.

The following procedure is used for the sensitivity analysis on the geo-political network in Figure 25:

1. The hub airport locations obtained with the geo-political method are maintained and will be used as the hubs for the new network.
2. The nodes are assigned to their closest hubs, rather than the hub within the cluster.
3. The flow is recalculated for the node-hub and the hub-hub links and the network is costed.
4. The changes in the node-hub and hub-hub flows and the costs for each link are shown in Table 22 below.

**Table 22: Comparison of networks for sensitivity analysis**

| Network type | Node-hub flow | Node-hub costs (US$) | Hub-hub flow | Hub-hub costs (US$) | Total costs (US$) |
|---|---|---|---|---|---|
| Geo-political network | 4 606 859 | 851 0 05 541 | 12 029 268 | 724 350 402 | 1 575 355 943 |
| Reassigned network | 4 270 224 | 866 279 175 | 12 365 903 | 708 559 563 | 1 574 838 738 |
| **% change** | **-7.88%** | **1.76%** | **2.72%** | **-2.18%** | **-0,03%** |

As expected, a decrease in the node-hub flow of 7,88% results in a 1,76% increase in costs due to the lower economies of scale transporting passengers to their hubs. Furthermore, as the hub-hub flow increases by 2,72%, there is a 2,18% decrease in the hub-hub costs due to the higher economies of scale enjoyed when transporting higher flows. The change in the total network costs when hubs are reassigned is shown to be negligible at 0,03%.

## 6.7 Cost Elasticity with Increasing Passenger Demand

The network equation derived by Klincewicz (1991) to calculate the hub network costs, shown in equation 11, has a term, $\alpha$, which represents the value by which costs are discounted on a route when it becomes a hub-hub link. The coefficient $\alpha$ in the literature was found to be about 0,75 for a US dataset, which implies that the costs on a link can be reduced by an average of 25% when that link becomes a hub-hub link in an H&S network. O'Kelly and Bryan (1998) comment that the oversimplification of the cost-reduction factor to a single value, as done in the literature, is not advisable as the value may not be uniform for all links. This section will be used to test whether the cost-reduction factor as assumed in the literature can be generalised, as is done in the literature. The costs per unit flow calculated for the inter-hub links in the various hub networks designed in this study will be compared with the O-D costs for the same links. The procedure is as follows:

- The 12 hub networks in this study are used to derive data for the operating cost per passenger for each of the hub-hub links in each network.
- For each of the hub-hub links in each network, the original O-D passenger numbers and sector distance are used to derive the costs, using the cost model.

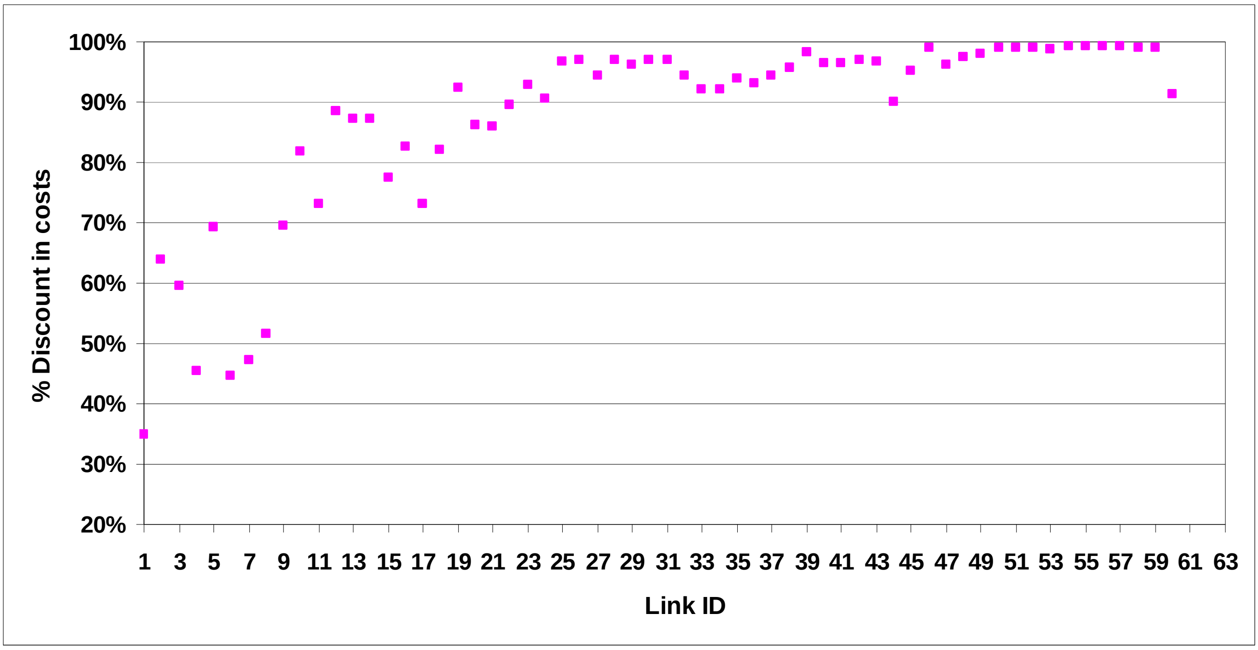



**Figure 27: % discount in cost per passenger for various hub-hub links**

Figure 27 illustrates the size of the discount for various links in the hub networks designed. From Figure 27 it can be seen that by assuming the discount of 75% as done in the literature, the costs on 95% of the links would have been overstated because their discount lies above the 75% mark. From the data, the average discount for the 62 links in the networks is 87%. This confirms O'Kelly and Bryan's statement that assuming a single discount for costs can lead to miscalculations of network costs. Therefore, using the cost model to recalculate costs as they reduce for each hub-hub link reduces the errors that could be incurred because the model recalculates the costs as the flow changes.

## 6.8 Summary

The factors discussed below have been found to be crucial in lowering costs when designing a hub network.

### 6.8.1 Node-hub costs

- The cheapest nodes to fly from are those nodes with high passenger numbers, which already enjoy economies of scale on the node-hub link.
- The more central the hub within the cluster, the lower the node-hub costs. This is because shortening the node-hub distances lowers costs through the use of smaller, cheaper aircraft.
- From the clustering, it is seen that node-hub costs decrease with the number of hubs in the network, due to the shorter node-hub distances.
- Node-hub costs constitute an average of about 58% of the final network costs, so they contribute a higher portion to lowering the total network costs.
- In order to lower node-hub costs, hubs with a combination of high passenger demand and short node-hub links should be chosen.

### 6.8.2 Hub-hub costs

- Hub-hub costs decrease with the number of hubs in the network. This is because networks with fewer hubs have fewer hub-hub links, so the higher passenger density results in better economies of scale.
- Shorter hub-hub links result in lower hub-hub costs because operating costs increase as sector distances increase.
- If a constant discount α, which represents the value by which costs are discounted on a route when it becomes a hub-hub link, is assumed (as done in the literature) the network costs would be wrong. The hub network data show that the links cost reductions for the different routes vary. Therefore, using the cost model to recalculate costs as they reduce for reach hub-hub link reduces the errors that could be incurred because the model recalculates the costs as the flow changes.

### 6.8.3 Hub network design costs

- The one-hub network works out the cheapest because of the short node-hub links – an average of 2 710 km to all points in the network. However, this hub network design is impractical because of the high passenger travel time expenditure incurred in routing all passengers via this hub.
- The optimum number of nodes for the region is found to be three or four hubs, because of the low node-hub costs.
- The most efficient network in Table 16 is the geo-political network, even though the geo-political method doesn't have the lowest node-hub costs or the hub-hub costs. However the network seems to achieve a good trade-off between the two and this ensures lower network costs. Furthermore, it combines cost effective factors of: high passenger demand, low sector distances, optimal aircraft types operating within their range thresholds, geopolitical factors that might influence airline hub location.
- In the short term, cheap options for hubs can be the airports with the highest passenger demand, because they have the benefits of better economies of scale that are realised with high passenger density on both node-hub and hub-hub routes. They also have the advantage of being better equipped with infrastructure, which would be a general problem within African airports in handling the increased number of passengers associated with hub networks.
- The sensitivity analysis shows that, as expected, when some of the nodes are reassigned to its closest hub, rather than the hub within the cluster, a decrease in the node-hub flow of 7,88% results in a 1,76% increase in costs. Conversely the hub-hub flow increases by 2,72%, there is a 2,18% decrease in hub-hub costs. The change in costs is due to the economies of scale that increase with higher traffic densities on routes. The change in the total network costs using the input factors of distance and passenger flow numbers when hubs are reassigned is shown to be negligible at 0,03%.
- The coefficient alpha in the literature, which represents the value by which costs are discounted on a route when it becomes a hub-hub link, would miscalculate costs if it were assumed to be constant. The assumption of a constant discount factor as done in some literature studies on the hub-hub costs would have been erroneous. From the data, the average discount for the 62 analysed links in the networks is 87% and varies from 35%-99%.

## 6.9 Sparse markets as hub-and-spoke air transport networks

This section defines sparse markets in air transport networks. The evaluation of how sparsity in air transport networks affects the design of efficient hub-and-spoke networks is carried out. Furthermore, the changes in the hub-and-spoke network design as the sparsity reduces will be discussed.

### 6.9.1 Definition

Chingosho (2005) explains that the sparsity of the network, with reference to Africa, is shown by the low number of trips per inhabitant per country or low air passenger demand per square kilometre. Alternatively, Andersson (2001) states that because the air transport industry is demand-responsive, the size of market in terms of average frequency of flights for routes has also been used to define the sparsity of a network. Pels et al. (2000) also define sparse markets using characteristics like thin routes which are served by low frequencies at extremely high costs of air travel.

One of the major characteristics of transport networks in sparsely populated regions identified by Andersson (2001) is that investments in transport infrastructure in such regions cause major political and budgetary conflicts. There is usually hardly any form of market competition in these regions because the airlines operate as pure monopolies as a consequence of high transport costs, inelastic passenger demand and sparse spatial distribution of demand.

### 6.9.2 Implication of the H&S design for sparse networks

This section deals with testing the benefits of hub-and-spoke network design within sparse markets. The development of a hub-and-spoke route network structure was adopted after deregulation in the US market. The hub-and-spoke structure was seen as a solution to decreasing the costs of travel and increasing frequency through competition. The network features of hub-and-spoke operations actually stimulate the provision of services to smaller communities. By funnelling traffic through hubs, it becomes viable to offer higher quality services to many smaller communities. In sparse networks, the traffic volumes on some of the routes for a direct service network would be so thin that services along these routes would not be commercially viable (Button et al., 2002).

The changes in a sparse network as passenger demand increases are tested by analysing the links in the geo-political network at the present passenger demand and at the passenger demand as sparsity reduces.

Table 23 shows that:

- At the current density, 86% of the nodes have an annual passenger demand of less than 300 000. With a 50% increase in demand, 80% of the links have between 300 000 and 1 000 000 passengers. With a 500% increase in demand, 97% of the N-H links have a demand of over 300 000 passengers. With a drastic increase in passenger demand of 500%, the percentage of node-hub links with an annual passenger demand greater than 1 000 000 passengers increases from 4% to only 32%. This gives a good indication of the sparsity of the African network in terms of passenger demand.
- The number of node-hub links that can be served with the smaller aircraft decreases to zero at a 500 % increase in passenger demand. The increase in operating costs is attributed to the large fleet that will be needed to meet the passenger demand. This makes the smaller-capacity aircraft less efficient as densities on routes increase.

- As density increases on routes in the geo-political network, larger aircraft with longer ranges operate more efficiently for short node-hub links. This shows that the node-hub distance becomes a less critical factor in lowering the costs because of the benefits of economies of scale as sparsity reduces.

**Table 23: Network analysis as passenger demand increases**

| Network Characteristics | Current Sparse Network | Hypothetical Network ( 50% increase in demand) | Hypothetical Network ( 500% increase in demand) |
|---|---|---|---|
| **Annual passenger demand** | **N-H links** | **N-H links** | **N-H links** |
| Less than 100 000 | 16 | 6 | 0 |
| Between 100 000 and 300 000 | 24 | 25 | 2 |
| Between 300 000 and 1 000 000 | 4 | 12 | 29 |
| Greater than 1 000 000 | 2 | 3 | 15 |
| **Aircraft with distance threshold<3 500 km** | **N-H links** | **N-H links** | **N-H links** |
| Embraer Erj 135 JET ( 37- seater) | 4 | 1 | 0 |
| Fokker F 50 (50-Seater) | 5 | 7 | 0 |
| **Aircraft with distance threshold<5 800 km** | **N-H links** | **N-H links** | **N-H links** |
| Boeing 737-400 | 22 | 17 | 20 |
| Airbus A320-200 | 15 | 20 | 26 |
| Boeing 737-800 | 0 | 1 | 0 |
| **Long-range aircraft** | **0** | **0** | **0** |

The most efficient and flexible aircraft to operate this network as passenger demand increases is either the Boeing 737-400 or the Airbus A320-200. This is because about 80% of the links are operated efficiently by these aircraft for the networks, either at current demand or at a 50% increase in demand. For the network with a 500% increase in demand, all the N-H links are operated efficiently using either of these aircraft. This fleet for this network would enjoy high utilisation hours as the aircraft can be assigned to most of the node-hub links.

### 6.9.3 Optimally efficient hub network design for sparse markets

The results of the study are summarised in this paragraph to give the ways in which an optimally efficient hub network, specific to sparse markets, can be designed. For sparse networks, the transmission flow costs were found to be cheapest for **hub-location options** which have high passenger demand. The **sector distance** is crucial in lowering operating costs in sparse markets as smaller, more efficient short-range aircraft can be operated. Since sector distances are crucial in lowering costs, the **optimum number of hubs/clusters** in sparse markets is determined by the distance threshold for the efficient aircraft. **Nodes are assigned** more efficiently to the hub within the cluster in order to lower node-hub costs by minimizing N-H distances. The effect of changing the **cluster boundaries** on network costs is also dependent on the change in node-hub distances between the clusters. Therefore, as long as the node-hub distances are below the lowest distance threshold of 3 500 km, smaller, more efficient aircraft can be operated.

### 6.9.4 Network changes as sparsity reduces over time

The general trend is that as **passenger numbers** increase, the benefits of economies of scale increase. This is because the costs per unit flow decrease exponentially as demand increases until they become constant. The benefits of economies of scale in networks with higher traffic densities allow for the efficient operation of **higher-capacity aircraft** as seen in Table 23**.**

As the passenger numbers increase, the node-hub links at higher passenger demand can be operated efficiently using aircraft with longer distance thresholds, as shown by Table 23. This implies that the **location of the hubs** can become more flexible as the node-hub distances increase due to the economies of scale with higher traffic densities. The longer node-hub links imply that the **numbers of hubs/clusters** in the network can decrease. This increases the **flexibility of the cluster boundaries** allowing for fewer clusters, fewer hubs and fewer hub-hub links. However, it would still not be practical to have a one-hub network on such a vast continent as Africa due to the high passenger travel time expenditure.

This discussion shows that sector distance and the use of an efficient aircraft are crucial in hub-and-spoke network design for sparse markets. As sparsity reduces, the economies-of-scale benefits outweigh the increasing operating costs felt with longer distances and the operation of larger-capacity aircraft. The effect of this on hub network design is that the location of the hubs becomes more flexible. Furthermore, network costs can then be minimised by decreasing the number of hubs and the number of clusters.

# CHAPTER 7: EFFECTIVENESS OF HUBBING

## 7.1 Introduction

This chapter investigates whether hubbing is a viable option for the sparse African network, based on the findings of this study. A comparison is carried out between the operations of a hub network and those of traditional airline networks. The traditional airline network operation that is investigated is limited to direct-flights operations for routes that are economically viable. This practice in the airline industry usually occurs when there are bilateral agreements between the origin and destination countries.

The comparison is done by analysing various O-D routes, using the results of the cost model, which focus on the route operating costs. The cost-effectiveness of operating a specific O-D route either by serving it directly or via hubs is compared. Specific criteria for passenger demand and sector distance are used to choose the O-D routes compared. The hub network used to compare operating costs in this investigation is that based on the geo-political method, being the cheapest hub network designed in the study. Fares will not be used as a basis of comparison between hub networks and traditional airline networks due to the incompleteness of data and the non-uniform pricing that results from practices such as predatory pricing and price discrimination. This method will highlight both the advantages and disadvantages of hubbing within Africa from the perspectives of both the operator and users, using specific cost and service indicators derived from the cost model.

### 7.1.1 Criteria for distinguishing between O-D pairs

Some of the findings of this study are that for any given O-D pair, the operating costs of transporting flow on that route depend on the passenger demand, the aircraft type and the sector distance. The O-D pairs to be compared will use the two defining parameters for route costs, which are *passenger demand* and *sector distance*. The passenger demand and sector distance data for each O-D pair in Africa are derived from the cost model database. Due to the effect of the economies of scale enjoyed with higher traffic density, O-D pairs with both high and low passenger demand are compared. Furthermore, since operating costs increase with increasing distances and the aircraft types used are limited by the distances to be flown, the sector distances will be defined as short-, medium- or long-haul routes. For the purposes of this study, short-haul routes are less than 3 500 km, medium-haul routes are between 3 500 km and 7 000 km, and long-haul routes are between 7 000 km and 12 000 km. These parameters are combined in the six O-D routes shown in Table 24 with examples of O-D routes that fit the specific criteria in terms of annual passenger demand and sector distance.

**Table 24: Route analysis**

| Route description | Examples | Annual No. of passengers | Route distance (km) |
|---|---|---|---|
| Short haul – Low passengers | CKY-COO | 1 082 | 1 796 |
| Short haul – High passengers | GBE-JNB | 96 722 | 293 |
| Medium haul – Low passengers | DKR-EBB | 1 008 | 5 721 |
| Medium haul – High passengers | NBO-FEZ | 45 710 | 5 868 |
| Long haul – Low passengers | TNR-NKC | 1 397 | 8 045 |
| Long haul – High passengers | JNB-CAI | 310 337 | 6 261 |

### 7.1.2 Cost and service indicators

This section will outline the indicators that are used to compare the types of transport service for the O-D pairs shown in Table 24. The transport operations compared are serving the O-D pair either as a direct flight or as a sector in a hub network. Under the hub network, passengers are routed to their final destination via hubs. The hub network that will be used to carry out the analysis is the geo-political network, which was found to be the cheapest hub network designed in the study. The operational indicators compared for the O-D pair, in terms of operating cost and service, are derived from the cost model. These indicators are:

- Most appropriate aircraft type serving the route
- Flight time for route from origin to destination
- Minimum weekly frequency needed to meet demand
- Fleet size needed to serve the route
- Weekly operating costs (US$) needed to serve the route
- Cost per passenger (US$) flying the route
- Cost per aircraft-km (US$) needed to serve the route
- Load factor as a profitability measure for the O-D pair.

These indicators for serving the six O-D pairs in Table 24 are compiled and compared based on the criteria distinguishing the sectors. This analysis will show whether hubbing is a viable option for both the service provider and the user.

## 7.2 Short-haul Route Analysis

Table 25 shows the results for the short-haul routes for both high and low passenger demand.

**Table 25: Service indicators for short-haul routes**

| | High Passenger Demand | | Low Passenger Demand | | |
|---|---|---|---|---|---|
| **Flight Type** | **Direct** | **Hub route** | **Direct** | **Hub route** | |
| **Route** | **GBE-JNB** | **GBE-JNB** | **CKY-COO** | **CKY-KAN** | **KAN-COO** |
| Aircraft type | Erj 135 jet | F-50 | Erj 135 jet | 737-400 | Erj 135 jet |
| Sector distance | 293 | 293 | 1 796 | 2 431 | 924 |
| Weekly passenger demand | 1 860 | 4212 | 21 | 4 026 | 1 385 |
| Flight time | 0,85 | 1,15 | 2, 66 | 3,48 | 1,61 |
| Minimum weekly frequency | 51 | 76 | 1 | 24 | 38 |
| Fleet size | 1 | 2 | 1 | 1 | 1 |
| Operating costs (US$/week) | 143 692 | 233 747 | 150 338 | 494 600 | 204 682 |
| Cost per passenger (US$) | 77 | 55 | 7 225 | 123 | 148 |
| Cost per aircraft-km (US$) | 10 | 10 | 84 | 8 | 6 |
| Load factor | 0,99 | 0,99 | 0, 56 | 1,00 | 0,99 |

The analysis of short-haul routes based on the results in Table 25 is given below:

- The route with a high passenger demand, GBE-JNB, with a distance of 293 km, can be served by short-range aircraft, at the same cost per aircraft-km, but with lower cost per passenger for the hub operation. The passenger demand for the O-D pair in the hub network is increased by 126% one of the stated advantages of hub networks. This leads to increased operating costs, increased fleet size and the need for increased frequency to meet the demand, as expected for routes with higher traffic densities.

The economies of scale enjoyed for the route are reflected in the decrease of 75% in the costs per passenger.

- For the O-D pair with low passenger demand, CKY-COO, the advantages of hubbing are shown explicitly. The average weekly passenger demand on this O-D pair in the hub network increases by 12 783%. This increases the frequency on the route from one flight per week operating at a 0,56 load factor to a minimum of 24 flights per week at a profitable load factor of 1. These high frequencies and the high passenger demand reduce both the costs per passenger and the costs per aircraft-km. However, the demerit of hubbing is shown by the extra travel time incurred because the flight time of the O-D route is doubled in the hub network.
- The advantages of hubbing on the short-haul route with low passenger demand are shown clearly. A traditional airline would not serve this route because the operating costs needed to meet the low demand make it unprofitable.
- The general advantage of flying short routes can be seen from the small fleet size needed to operate both the O-D pairs of high and low passenger demand. Even when the frequency of flights increases with increasing passenger demand in the hub network, the fleet size remains small because the flights are shorter. For example, 137-seater Embraer Erj-135 Jet can serve a frequency of 51 flights a week for 1 860 passengers on a 293 km route of GBE-JNB.

## 7.3 Medium-haul Route Analysis

Table 26 shows the results for medium haul routes for both high and low passenger demand.

**Table 26: Service indicators for medium-haul routes**

| **Parameters** | **High Passenger Demand** | | **Low Passenger Demand** | | | |
|---|---|---|---|---|---|---|
| **Flight Type** | **Direct** | **Hub route** | **Direct** | **Hub route** | | |
| **Route** | **NBO-FEZ** | **NBO-FEZ** | **EBB-DKR** | **EBB-NBO** | **NBO-KAN** | **KAN-DKR** |
| Aircraft type | 767-200 | 767-200 | 767-200 | F-50 | A 320-200 | 737-400 |
| Sector distance | 5 868 | 5 868 | 5 721 | 521 | 3 469 | 2 826 |
| Weekly passenger demand | 879 | 19 408 | 19 | 2 424 | 22 265 | 3 750 |
| Flight time | 7,40 | 7,40 | 7,62 | 1,66 | 4,66 | 3,97 |
| Minimum weekly frequency | 4 | 77 | 1 | 44 | 124 | 23 |
| Fleet size | 1 | 6 | 1 | 2 | 7 | 1 |
| Operating costs (US$/week) | 459 210 | 2 423 862 | 315 159 | 203 498 | 1 465 118 | 505 767 |
| Cost per passenger (US$) | 523 | 125 | 16 258 | 84 | 66 | 135 |
| Cost per aircraft-km (US$) | 20 | 5 | 55 | 9 | 3 | 8 |
| Load factor | 0,99 | 0,99 | 0,08 | 0,98 | 100 | 0,97 |

- For the high passenger demand route, the O-D pair chosen of NBO-FEZ is a hub-hub link in the geo-political network. This route was investigated to explore the effects of turning a high passenger demand O-D pair into a hub-hub link. The advantages of increased traffic densities for hub networks are reaffirmed on this route as passenger demand increases by 2 107%. The weekly frequency of flights on the route increases from 4 to 77, increasing both the fleet size and operating costs needed to serve the route in the hub network.
- The load factor, the aircraft type and the flight time for the NBO-FEZ route are constant, whether it is operated as a direct route or as an inter-hub route. However, the advantage of operating this route in the

hub network, even with increased operating costs, is seen in the economies of scale enjoyed with higher traffic densities. Due to these higher traffic densities, the costs per passenger reduce from US$523 to US$125, implying that the operating costs are spread over more passengers as more revenue is gained in the hub network.

- Operating the low passenger demand O-D pair, EBB-DKR, as a direct route requires a service of one flight a week to serve the 19 passengers, at an unprofitable load factor of 0,08. The 255-seater plane will be operated at a high cost per passenger of US$16 258 because of the low passenger demand. However, when this route is operated in a hub network, increased passenger numbers, flight frequencies and load factors makes it profitable to operate at a lower average cost per passenger of US$95.
- Even though this flight is profitable in a hub network, the disadvantage of hubbing would be felt by the passengers through the extra travel time incurred. The flying time for the direct route from EBB to DKR is 7,62 hours, whereas the total travel time in a hub network is 10,29 hours . This travel time excludes waiting time for connecting flights, a common practice at hub airports. This shows the inconvenience that passengers are faced with when they have to fly routes of considerable length through a hub network.

## 7.4 Long-haul Route Analysis

Table 27 shows the results for long-haul routes for both low and high passenger demand.

**Table 27: Service indicators for long-haul routes**

| | Low Passenger Demand | | | | High Passenger Demand | | |
|---|---|---|---|---|---|---|---|
| **Flight Type** | **Direct** | **Hub route** | | | **Direct** | **Hub route** | |
| **Route** | **TNR-NKC** | **TNR-JNB** | **JNB-FEZ** | **FEZ-NKC** | **JNB-CAI** | **JNB-FEZ** | **FEZ-CAI** |
| Aircraft type | 767-200 | A320-200 | 767-200 | Erj 135 | 767-200 | 767-200 | A 320-200 |
| Sector distance | 8045 | 2 134 | 7 538 | 2 069 | 6 261 | 7 538 | 3 436 |
| Weekly passenger demand | 27 | 12 231 | 46 164 | 1 269 | 5 968 | 46 164 | 23 885 |
| Flight time | 9,96 | 3,06 | 9,37 | 2,98 | 7,87 | 9,37 | 4,62 |
| Minimum weekly frequency | 1 | 68 | 10 | 35 | 14 | 182 | 133 |
| Fleet size | 1 | 3 | 1 | 2 | 2 | 14 | 7 |
| Operating costs (US$/week) | 612 819 | 789 318 | 866 275 | 362 554 | 1 355 684 | 6 090 277 | 1 549 586 |
| Cost per passenger (US$) | 22 811 | 65 | 357 | 286 | 198 | 132 | 65 |
| Cost per aircraft-km (US$) | 76 | 5 | 11 | 5 | 8 | 4 | 3 |
| Load factor | 0,11 | 1,00 | 0,95 | 0,98 | 0,98 | 0,99 | 1,00 |

- The low passenger demand O-D route chosen, TNR-NKC, also highlights the benefits of consolidating passengers, which lowers the costs per unit flow on a route. Operating the O-D pair as a direct route implies that the demand of 27 passengers is flown unprofitably at a low load factor of 0,11. However, in a hub network the load factor increases to an average of 0,98 for both legs of the journey. This O-D pair also shows that hubbing increases accessibility within the continent due to increased flight frequency. As a direct flight, the minimum service frequency needed to meet demand is one flight per week, whereas in a hub network the frequency increases to 68 flights on the first leg (TNR-JNB).
- The extra travel time incurred by passengers from their origin to their destination in a hub network, especially for routes with low passenger demand, is outweighed by the increased accessibility and lower

fares. This is because these O-D pairs cannot be operated profitably as direct routes because of the low passenger demand on the routes.

- The findings for the high passenger demand O-D route, JNB-CAI, are interesting. As a direct flight service option, the O-D pair is a lucrative route with a high weekly frequency of 14 flights and a fleet size of two aircraft flying at a high load factor of 0,98. Serving the O-D pair as a route in a hub network works at a disadvantage, because the total flight time is 13,99 h, which is a lot longer than the direct flying time of 7,87 h.
- Even though the JNB-CAI route is profitable in operations either as a direct route or as a route in a hub network, the hub network option is at a disadvantage. The service indicators for the direct flight option show that the route can also be operated as a direct route, rather than routing the passengers through hubs. This is because it is more attractive option for the passengers when operated directly due to the high flight frequencies and shorter travel time. This route highlights the need, when designing a hub network, for flexibility to allow direct flights for those routes that can be flown profitably in order to avert competition and limit passenger inconvenience.

## 7.5 Summary

Table 28 summarises the merits and demerits of hubbing that are highlighted in the route analysis for the various O-D pairs in the geo-political hub network.

**Table 28: Summary of the effectiveness of hubs**

| **Merits of Hubbing** | |
|---|---|
| Economies of scale | Hub networks operate by consolidating passengers from their origin to their destination through hubs. This is because the first leg of the route includes all passengers flying to and from the origin, and the last leg of the journey includes all passengers flying to and from the destination. Routes on a hub network generally enjoy economies of scale, which are realised through transporting higher traffic densities, thus lowering the costs per unit flow. |
| Higher flight frequencies | The consolidation of passengers on routes in a hub network implies that the minimum flight frequencies needed to meet the increased number of passengers are higher, improving accessibility. This is shown explicitly for O-D pairs with low passenger demand, which would otherwise be served by low flight frequencies in a direct flight option. |
| Better capacity allocation | Due to the lower costs per unit flow enjoyed when operating routes in a hub network, more appropriate aircraft can be used. Furthermore, the increased frequency of flights and high load factors improve aircraft utilisation. Shorter node-hub routes benefit more from the use of cheaper aircraft, even with the high flight frequencies in a hub network. |
| Lower cost of travel | The economies of scale enjoyed through higher traffic densities are achieved through hubbing. This implies that the lower costs per unit flow will allow airlines to charge lower fares on a route. The lower fares enjoyed in a hub network attract passengers, who value the cost savings more than the extra travel time incurred by flying through hubs. |

| | |
|---|---|
| Increased accessibility | There are increased flight frequencies in a hub network, which are necessary to meet the higher passenger demand. This implies that passengers have more options for flights times from their origin nodes to their destination nodes in a hub network. |

| **Demerits of Hubbing** | |
|---|---|
| Increased travel time | The travel time for O-D pairs in a hub network increases, especially for medium- and long-haul routes. This is because the O-D movement in this network entails routing passengers via one or two hubs before they reach their final destination. There is also the inconvenience of time spent at airports waiting for connecting flights, which increases the total travel time for a hub network as compared with a direct flight. |
| Additional running costs | The additional running costs in a hub network include the extra landing and take-off costs incurred while routing passengers. The longest O-D route in a hub network becomes a three-leg route because all passengers are connected through hubs. This origin-hub-hub-destination mode has three times as many aircraft changes, landing costs, take-off costs, passenger handling fees, crews and maintenance checks. |
| Congestion at airports | With the increased number of flights and the increased accessibility on all legs in the hub network, there is an increasing likelihood of congestion. Schedules and slot times for hub airports worldwide are very inflexible, such that delays become a common problem. Even with more runways, taxiways and gates, congestion and schedule delays are inevitable due to the higher capacity, especially at hub airports. |

# CHAPTER 8: CONCLUSIONS AND RECOMMENDATIONS

## 8.1 Conclusions

The purpose of this research was to investigate cost-effective H&S network design strategies for the sparse travel demand in Africa. The main purpose of the H&S network was to minimise the cost of air transport, for both the operator and the user, in a bid to lower the costs of setting up a regional airline service. The study involved two major parts:

1. Designing a cost effective H&S network for a regional airline service to meet passenger demand.
2. Investigating whether an H&S network arrangement is a viable option for both the users and the operator of the airline service, in terms of indicators such as costs, service frequency and time factors.

The results of the research will contribute to the understanding of the H&S network arrangement as it pertains to the African situation, with regard to both the hub-location method and optimum hub network service design. On a broader perspective, other potential sparse-demand markets can use this study as a guideline for investigating the feasibility of creating hub networks for airline services where sector distances are high and passenger demand is low. The major conclusions that were derived for this study are discussed below.

### 8.1.1 Opening up the skies

For any regional expansion of airlines within the African continent, faster progression of the Yamoussoukro Decision (YD) of 1988 needs to take place so that open skies, free competition rules and Fifth Freedom rights will be granted. The most practical thing to do would be for airlines to join alliances, or unify on a regional basis, so that even though the expansion of the airline industry is political, government involvement is limited to trying to negotiate routes and airline service agreements.

### 8.1.2 Application of the cost model to hubbing

The cost model that was developed to calculate route operating costs was successfully applied to test the economies of scale that can be enjoyed as passenger number increase in H&S networks.

### 8.1.3 Network design method

After the cost model had been used to test these economies of scale, the method for designing an H&S network for the African continent was defined as follows:

- The hub location was defined as the ρ-hub median problem, where a fixed number of hubs (ρ) are chosen from the nodes (n).
- The node allocation was solved as the uncapacitated single-allocation ρ-hub median problem, which implies that each node is assigned to only one hub. The passengers from the origin node will connect via the closest hub airport to route them to their destination nodes.

- The network was costed using equation 15, which calculates the cost of routing all passengers from each node to the closest hub and then to their final destinations. The costs and flows needed for the calculation were derived from a cost model that calculates route-operating costs for Africa-specific data.

### 8.1.4 Hub-location strategies

The methods that are used to locate the most cost-effective hubs set the networks apart from each other. Each network is defined based on the method used for choosing hubs and once the hub location has been determined, the nodes are allocated and the network costs are calculated. The following strategies were used to locate the hubs that would possibly provide the lowest network cost:

1. The one-hub network ($\rho$ = 1) of n = 50 nodes, which involves choosing the nodes that lower the costs of passenger movement. Therefore, in the $\rho$ = 1 hub network all passengers are routed from origin to destination through just the one hub.
2. The method of clustering, which involves dividing large networks into clusters, where each cluster comprises the nodes within that specific area. The cluster method was used to investigate:
    a. The optimum number of hubs for the African network.
    b. The optimum location of hubs in clusters using the following methods:
        - The Klincewicz method of hub location, where the probability of a node becoming a hub in a cluster is based on shortest distances and high passenger numbers.
        - The modified Klincewicz clustering method, in which the probability of a node becoming a hub in a cluster is based on its operating costs, which are derived from the cost model.
3. Calculation of the costs per passenger and costs per aircraft-km, on each O-D link in the 50-by-50 matrix, using the cost model. Thereafter, the nodes which had the lowest total costs were used as hub-location options.
4. The geo-political method, which assesses all the airports that are well positioned, both politically and geographically, and are justified as suitable hub airports.

### 8.1.5 Hub network analysis

The H&S networks designed above were analysed in terms of costs to draw inferences as to how to design an H&S network that will lower airline operating costs and network costs. The general inferences drawn were:

- The ***one-hub network*** has only node-hub links and turned out to be the network with the lowest costs. The disadvantage, though, is that the passenger travel time expenditure is high, causing inconvenience to the passengers. It would also be impractical to fly passengers through one central hub.
- From the ***optimum clustering method*** it was found that as the clusters in a network increase, the size of the clusters decreases. Therefore, as cluster size decreases, the passenger demand in each cluster reduces. Furthermore, the average flow for the node-hub link decreases as the number of clusters increases. The shorter distances should reduce the costs per unit flow as clusters increase, but the passenger demand also decreases. The decreasing passenger demand in the clusters therefore reduces the economies of scale, so that the five-cluster network has the highest node-hub costs.
- From the ***total network costs*** it was found that the optimum network for the continent would be either a four-hub network or a three-hub network because these have the lowest costs.

- Application of ***Klincewicz's method*** shows that the airports that have high passenger numbers, such as ALG, JNB and ADD, are constantly chosen as hubs in their clusters, irrespective of the hub-location method and the number of clusters. The nodes characterised by high passenger demand are already attractive in terms of distances and passenger numbers, and thus have lower node-hub costs.
- The ***modified Klincewicz's method*** of using cost-per-passenger indexes results in cheaper node-hub costs than Klincewicz's method. This is because the modified method favours those hubs that have the cheapest calculated costs of transmitting flow within the cluster.
- A ***percentage analysis of costs*** carried out for all the networks calculated showed that, on average, the node-hub costs contribute about 58% to the total costs, while the hub-hub costs contribute only 42% to the network costs. This confirms O'Kelly and Bryan's (1998) findings that the hub-hub portion of the trip costs less than the spoke portion. Therefore, a network has an incentive to connect the nodes to the hubs as quickly as possible in order to take advantage of the lower hub-hub costs.
- The ***node-hub analysis*** showed that hubs with higher passenger demand have cheaper node-hub costs due to economies of scale. Networks with short inter-hub links lower hub costs because operating costs increase as distances increase. In order to lower network costs, the strategic location of the hubs within the clusters to shorten links combined with the economies of scale achieved through high traffic volumes are essential factors.
- As can be seen from Table 16, the most efficient network is the **geo-political network**. It has low node-hub costs and even though it does not have low hub-hub costs, the network seems to achieve a good trade-off between the two costs. It also combines the following factors: high passenger demand, low sector distances, optimal aircraft types operating within their range thresholds and geopolitical factors that might influence airline hub location. Furthermore, the total passenger travel time expenditure in this network is among the lowest, making it a convenient route network for passengers.
- The ***sensitivity analysis*** shows that when some of the nodes are reassigned to their second-closest hub, as expected, a decrease in the node-hub flow of 7,88% results in a 1,76% increase in costs due to the longer distances involved in transporting flows to their hubs. On the other hand, as the hub-hub flow increases by 2,72%, there is a 2,18% decrease in hub-hub costs due to the economies of scale enjoyed when transporting higher flow. The change in the total network costs using the input factors of distance and passenger flow numbers when hubs are reassigned is shown to be negligible at 0,03%.
- The ***coefficient alpha*** in the literature, which represents the value by which costs are discounted on a route when it becomes a hub-hub link, would miscalculate costs if it were assumed to be constant. The assumption of an average reduction factor as done in some literature studies on the hub-hub costs would have been erroneous. From the data, the average discount for the 62 analysed links in the networks is 87% and varies from 35%-99%.
- The results of the study are summarised in this paragraph to give the ways in which an ***optimally efficient hub network, specific to sparse markets***, can be designed. For sparse networks, the transmission flow costs were found to be cheapest for hub-location options which have high passenger demand. The sector distance is crucial in lowering operating costs in sparse markets, as smaller, more efficient short-range aircraft can be operated. Since sector distances are crucial in lowering costs, the optimum number of hubs/clusters in sparse markets is determined by the distance threshold for the efficient aircraft. Nodes are assigned more efficiently to the closest hub in order to lower node-hub costs by minimizing N-H distances. The effect of changing the cluster boundaries on network costs is also dependent on the change in node-hub distances between the clusters. Therefore, as long as the node-hub

distances are below the lowest distance threshold of 3 500 km, smaller, more efficient aircraft can be operated.

- As **sparsity reduces**, the economies-of-scale benefits outweigh the increasing operating costs felt with longer distances and the operation of larger-capacity aircraft. The effect of this on hub network design is that the location of the hubs becomes more flexible. Furthermore, network costs can then be minimised by decreasing the number of hubs and the number of clusters.

### 8.1.6 Hubbing versus direct flights

From the analysis of whether to fly direct or to consolidate flow through hubbing on a route, the following conclusions were drawn for specific sectors:

1. The general advantage of flying ***short routes*** is that a small fleet size is needed to operate the O-D pairs with both high and low passenger demand. Even when the frequency of flights increases with increasing passenger demand in the hub network, the fleet size will remain small because the flights are shorter.
2. The advantages of hubbing for ***routes with low passenger demand*** are very apparent. A traditional airline would not serve these routes because the operating costs needed to meet the low demand make them unprofitable. Accessibility within the continent would actually increase with hubbing due to the fact that the flight frequency of the airlines would increase, which is an advantage to users of the service because they have more options. The hub network allows flexibility of planning and operations for the service provider, with adequate utilisation of aircraft on routes with reasonably high load factors, yielding profitability in a market of scarce passenger demand.
3. The disadvantage of the ***extra travel time*** incurred by passengers from their origin to their destination in a hub network, especially on routes with low passenger demand, is outweighed by increased accessibility and lower fares. These O-D pairs cannot be operated profitably as direct routes because of the low passenger demand on the routes.
4. Some of the ***high passenger demand routes*** can be operated profitably either as direct routes or as routes in a hub network. The service indicators for the direct flight option show that the route would be more lucrative if run as a direct route, rather than routing the passengers through hubs. This is because for the passengers a direct flight option is more attractive due to the high frequencies and shorter travel times. This highlights the need to be flexible when designing a hub network to allow direct flights on those routes that can fly profitably to avert competition and limit passenger inconvenience.

## 8.2 Recommendations

The scope of the study excludes the following factors which are relevant to the airline industry:

- **Competition**: This is a realistic barrier to yield, market growth and profitability on routes. Elements and practices of competition drive fares and quality of services, which in turn influences demand on a route.
- **Airport capacity**: Ignoring the capacity of airports, especially hubs, implies that the slots, runways and gates have unlimited capacity. In the literature issues of congestion, delay and scheduling with time are used as critical elements in the selection of hub airports.
- **Infrastructure costs**: Limiting the study to only the direct operating costs excludes the cost of setting up the infrastructure in a region where airport infrastructure is already inadequate. The cost of the

infrastructure is recouped by the airports through the landing fees, passenger handling charges and parking fees, which cost is ultimately born by the consumer.

- **Environmental costs**: It is pertinent that the implications of designing an H&S network are tested to assess the detrimental effect of air transport on the environment. The advantages of the H&S network include increased frequency and connectivity through flying. This has a negative environmental impact in terms of pollution through noise and gas emissions.

The methods that were used to design an H&S network in this thesis used a mechanistic model to calculate the route costs and the network costs. There is need for a non-mechanistic method to be designed to find an optimum solution to the ρ-hub median problem for the Africa network. There are various hub-location methods that have not been used in this study because of the cumbersome nature of the mechanistic method of network design that was adopted. Some of the methods that could be investigated for hub location are listed below.

- ***Heuristics*** uses the problem-solving technique of selecting the most appropriate solution among several found by alternative methods at successive stages of a computer program for use in the next step of the program. This method could be used to investigate features such as flow-threshold, capacity restrictions, cheapest node-hub costs and cheapest hub-hub costs.
- The ***Tabu-search*** and ***genetic algorithm*** procedure could be used because it is an iterative procedure that moves from one feasible solution to another. This procedure would involve costing all the possible combinations of hubs, until the cheapest combination of hubs is found. It would require the automation of the hub location, node allocation and network costing procedure.
- A ***linear program*** could be used to solve the problem, especially if the variation in demand depending on the costs could be quantified. The costs for each route as it becomes a hub-hub link could be calculated so that the costs would not have to be inserted manually into equation 12 for all the possible networks.

The clustering method has proved a very useful tool for analysing the node-hub costs and the hub-hub costs in relation to sector distance and passenger demand. The next step, then, would be to try to ascertain which of the two factors has a greater effect, since Klincewicz's method assumes that the two factors contribute equally to hub location.

In conclusion, very few studies have focused on the potential or actual benefits of hub-and-spoke operations outside of US and European markets. Africa is used as an exemplar of a very sparse market, where thin flows typically result in infrequent air service at very high costs. The methodology is unique in that it incorporates the cost model. This cost model allows the user to explicitly estimate the costs of transporting flow, based on demand and distances. It also eliminates errors made by assuming discount costs. The main aim of the study was to establish the hub network with the lowest network costs, appropriate for the African route network. This study through analysing various hub networks analyses the various H&S network design processes that will lower network costs for sparse markets. These factors include optimising the number of clusters, high passenger demand at hubs, shortening sector distances, operating cheaper aircraft and geo-political elements. It is hoped that this work will be useful to airline operators, researchers and policy makers.

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# APPENDICES

Appendix I: Demographical details of all African countries.

| | COUNTRY | CAPITAL | INT'L AIRPORTS | CODE |
|---|---|---|---|---|
| 1 | Algeria | Algiers | Algiers | ALG |
| 2 | Angola | Luanda | Luanda | LAD |
| 3 | Benin | Porto Novo | Porto Novo(Cotonou) | COO |
| 4 | Botswana | Gaborone | Gaborone | GBE |
| 5 | Burkina Faso | Ouagadougou | Ouagadougou | OUA |
| 6 | Burundi | Bujumbura | Bujumbura | BJM |
| 7 | Cameroon | Yaounde | Nsimalen International | NSI |
| 8 | Cape Verde Islands | Prata | Amil Cabral Int'l Airport | SID |
| 9 | Central African Republic | Bangui | Bangui (M'poko) | BGF |
| 10 | Chad | N'Djameni | N'Djameni | NDJ |
| 11 | Comoros | Comoros | Comoros International airport | COM |
| 12 | Congo Dem. Rep | Kinshasa | Kinshasa(Ndjili) | FIH |
| 13 | Congo. Rep. | Brazaville | Brazaville(MayaMaya) | BZV |
| 14 | Cote D'Ivoire | Abidjan | Abidjan (Port Bouet) | ABJ |
| 15 | Djibouti | Djibouti | Djibouti- Ambouli | JIB |
| 16 | Egypt | Cairo | Cairo | CAI |
| 17 | Equatorial Guinea | Malabo | Malabo Airport | SSG |
| 18 | Eritrea | Asmara | Asmara(Yohannes IV) | ASM |
| 19 | Ethiopia | Addis Ababa | Addis Ababa | ADD |
| 20 | Gabon | Libreville | Libereville | LBV |
| 21 | Gambia, The | Banjul | Banjul | BJL |
| 22 | Ghana | Accra | Accra | ACC |
| 23 | Guinea | Conakry | Conakry-Gbeissa | CKY |
| 24 | Guinea Bissau | Bissau | Bissau - Osvaldo | BXO |
| 25 | kenya | nairobi | Nairobi | NBO |
| 26 | Lesotho | Maseru | Maseru- Moshoeshoe | MSU |
| 27 | Liberia | Monrovia | Roberts Int'l | ROB |
| 28 | Libya | tripoli | Tripoli(Idris) | TIP |
| 29 | Madagascar | Antananarivo | Antananarivo(Ivato) | TNR |
| 30 | Malawi | Lilongwe | Lilongwe-senou | LLW |
| 31 | Mali | Bamako | Bamako | BKO |
| 32 | Mauritania | Nouakchott | Nouakchott | NKC |
| 33 | Mauritius | Mauritius | Mauritius | MRU |
| 34 | Morocco | Rabat | Fes Saiss Int'l airport | FEZ |
| 35 | Mozambique | maputo | Maputo | MPM |
| 36 | Namibia | Windhoek | Windhoek(eros) | WDH |
| 37 | Niger | Niamey | Niamey | NIM |
| 38 | Nigeria | Abuja | Kanu-Mallam Amim | KAN |
| 39 | Rwanda | Kigali | Kigali | KGL |
| 40 | Sao Tome & principe | Sao Tome | Sao Tome | TMS |
| 41 | Senegal | Dakar | Dakar | DKR |
| 42 | Sierra Leone | Freetown | Freetown(lungi Airport) | FNA |
| 43 | Somalia | Mogadishu | Mogadishu | MGQ |
| 44 | South Africa | Pretoria | Johannesburg | JNB |
| 45 | Sudan | Khartoum | Khartoum | KRT |
| 46 | Tanzania | Dar es salaam | Dar es salaam | DAR |
| 47 | Togo | Lome | Lome- Tokoin | LFW |
| 48 | Tunisia | Tunis | Tunis(Carthage Airport) | TOE |
| 49 | Uganda | Kampala | Entebbe | EBB |
| 50 | Zambia | Lusaka | Lusaka | LUN |
| 51 | Zimbabwe | Harare | Harare | HRE |

Appendix II: Input Sheet for a 2944km route with weekly passenger demand of 577 (Route Cost Model)

| | A | B | C | D | E |
|---|---|---|---|---|---|
| 1 | **SITUATION INPUT** | | | | |
| 2 | | **Country** | **Route** | **Codes** | **Column & Row No** |
| 3 | **From** | Uganda | **Origin airport** | EBB | 16 |
| 4 | **To** | South africa | **Destination airport** | JNB | 23 |
| 5 | | | | | |
| 6 | **Passenger trips** | **Automatic** | **Manual** | | |
| 7 | **Annual Passenger Numbers** | 39,166 | 30000 | | |
| 8 | **Weekly Passenger Numbers** | 753 | 577 | | |
| 9 | | | | | |
| 10 | **Trip length (km)** | **Automatic** | **Manual** | | |
| 11 | **Sector Distance** | 2,944 | | | |
| 12 | | | | | |
| 13 | | | **Minimum weekly service frequency** | | |
| 14 | **Modes** | **Abbreviation** | **Automatic** | **Manual** | |
| 15 | Embraer Erj 135 JET | ERJ 135 | 16 | | |
| 16 | Fokker F 50 | F- 50 | 11 | | |
| 17 | Boeing 737-200 | 737-200 | 5 | | |
| 18 | Boeing 737-400 | 737-400 | 4 | | |
| 19 | Airbus A320-200 | A320-200 | 4 | | |
| 20 | Airbus A340 -200 | A340 -200 | 2 | | |
| 21 | Boeing 737-800 | 737-800 | 4 | | |
| 22 | Boeing 767-200 | 767-200 | 3 | | |
| 23 | Boeing 747-200 | 747-200 | 2 | | |
| 24 | Boeing 767-300ER | 767-300ER | 2 | | |
| 25 | Boeing 747-400 | 747-400 | 2 | | |

Appendix III: Calculation Sheet for a 2944km route with weekly passenger demand of 577 (Route Cost Model)

| | A | B | C | D | E | F | G | H | I | J | K | L |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | **ROUTE CHARACTERISTICS** | **Erj 135 JET** | **F 50** | **737-200** | **737-400** | **A320-200** | **A340 200** | **737-800** | **767-200** | **747-200** | **767-300ER** | **747-400** |
| 2 | **Weekly Passenger Demand (No)** | 577 | 577 | 577 | 577 | 577 | 577 | 577 | 577 | 577 | 577 | 577 |
| 3 | **Minimum service frequency (Demand)** | 16 | 11 | 5 | 4 | 4 | 2 | 4 | 3 | 2 | 2 | 2 |
| 4 | **Sector Distance (km)** | 2944 | 2944 | 2944 | 2944 | 2944 | 2944 | 2944 | 2944 | 2944 | 2944 | 2944 |
| 5 | **Block time (hrs)** | 4.03 | 7.07 | 4.37 | 4.11 | 4.03 | 3.92 | 4.14 | 3.96 | 3.79 | 3.78 | 3.72 |
| 6 | **Round-trip time (hrs)** | 9.87 | 15.94 | 10.55 | 10.02 | 9.87 | 9.64 | 10.07 | 9.73 | 9.38 | 9.36 | 9.24 |
| 7 | **Maximum daily service frequency (Supply)** | 4 | 2 | 3 | 3 | 4 | 4 | 3 | 4 | 4 | 4 | 4 |
| 8 | **Maximum weekly service frequency( supply)** | 28 | 14 | 21 | 21 | 28 | 28 | 21 | 28 | 28 | 28 | 28 |
| 9 | **Fleet size needed to meet demand (No)** | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 |
| 10 | **Weekly utilisation (hrs)** | 64.55 | 77.79 | 21.87 | 16.45 | 16.14 | 7.84 | 16.55 | 11.89 | 7.58 | 7.56 | 7.44 |
| 11 | **Annual Utilisation (hrs)** | 3,356 | 4,045 | 1,137 | 855 | 839 | 408 | 860 | 618 | 394 | 393 | 387 |
| 12 | **STANDING COSTS (per hr utilised)** | | | | | | | | | | | |
| 13 | **Hourly Depreciation (US$)** | 566 | 717 | 3,693 | 3,367 | 3,647 | 17,811 | 3,940 | 8,442 | 22,837 | 30,051 | 28,683 |
| 14 | **Hourly Insurance (US$)** | 170 | 215 | 1,108 | 1,684 | 1,823 | 8,906 | 1,970 | 4,221 | 11,419 | 15,025 | 14,342 |
| 15 | **Hourly Interest (US$)** | 272 | 344 | 1,773 | 2,604 | 2,820 | 13,774 | 3,047 | 6,529 | 17,661 | 23,239 | 22,182 |
| 16 | **TOTAL STANDING COSTS** | 664 | 1,013 | 1,467 | 1,285 | 1,365 | 3,239 | 1,512 | 2,329 | 4,015 | 5,273 | 4,952 |
| 17 | **FLYING COSTS (per hr utilised)** | | | | | | | | | | | |
| 18 | **Fuel (while climbing) (US$)** | 166 | 113 | 539 | 482 | 475 | 1,151 | 498 | 968 | 2,260 | 1,134 | 1,945 |
| 19 | **Fuel (while cruising) (US$)** | 261 | 177 | 848 | 757 | 747 | 1,808 | 782 | 1,521 | 3,552 | 1,782 | 3,056 |
| 20 | **Crew costs (US$)** | 275 | 274 | 317 | 355 | 357 | 381 | 358 | 371 | 459 | 416 | 463 |
| 21 | **Direct Maintenance (US$)** | 666 | 843 | 4,343 | 6,599 | 7,148 | 34,910 | 7,722 | 16,547 | 44,761 | 58,900 | 56,219 |
| 22 | **TOTAL FLYING COSTS** | 1,368 | 1,407 | 6,047 | 8,194 | 8,727 | 38,250 | 9,360 | 19,407 | 51,032 | 62,232 | 61,683 |
| 23 | **TOTAL DIRECT OPERATING COSTS** | 2,032 | 2,420 | 7,514 | 9,478 | 10,092 | 41,489 | 10,872 | 21,736 | 55,047 | 67,505 | 66,635 |
| 24 | **OTHER COSTS** | | | | | | | | | | | |
| 25 | **Landing Fees( US$ per week)** | 208 | 121 | 1480 | 1408 | 1596 | 2514 | 1596 | 2370 | 3706 | 3632 | 3762 |
| 26 | **Parking Fees (US$ per week** | 154 | 133 | 259 | 259 | 259 | 532 | 259 | 469 | 672 | 525 | 672 |
| 27 | **Passenger Handling (US$ per week)** | 3,462 | 3,462 | 3,462 | 3,462 | 3,462 | 3,462 | 3,462 | 3,462 | 3,462 | 3,462 | 3,462 |
| 28 | **Ticketing, sales and commission (per hr utilised)** | 539 | 642 | 1,994 | 2,516 | 2,678 | 11,012 | 2,886 | 5,769 | 14,610 | 17,917 | 17,686 |
| 29 | **General administrative costs (per hr utilised)** | 212 | 253 | 785 | 990 | 1,054 | 4,334 | 1,136 | 2,270 | 5,750 | 7,051 | 6,960 |

Appendix IV: Output Sheet for a 2944km route with weekly passenger demand of 577 (Route Cost Model)

| | B | D | E | F | G | H | I | J |
|---|---|---|---|---|---|---|---|---|
| | **Erj 135 JET** | **737-200** | **737-400** | **A320-200** | **A340 200** | **737-800** | **767-200** | **747-200** |
| **Aircraft suitablity** | Yes | Yes | Yes | Yes | Yes | Yes | Yes | Yes |
| **Route Productivity** | 833.00 | 760.00 | 815.00 | 833.00 | 861.00 | 809.50 | 850.00 | 895.00 |
| **ONE-WAY TRIP COSTS** | | | | | | | | |
| **Standing costs** | 2,677 | 6,416 | 5,283 | 5,507 | 12,693 | 6,256 | 9,230 | 15,214 |
| **Flying costs** | 4,825 | 24,013 | 31,644 | 33,219 | 145,240 | 36,589 | 72,946 | 184,492 |
| **Other costs** | 3,271 | 13,196 | 15,698 | 16,387 | 63,396 | 17,964 | 33,964 | 81,071 |
| **TOTAL COSTS** | 10,773 | 43,625 | 52,626 | 55,113 | 221,330 | 60,809 | 116,140 | 280,777 |
| **WEEKLY ROUTE COSTS** | | | | | | | | |
| **Standing costs** | 42,837 | 32,082 | 21,133 | 22,028 | 25,387 | 25,024 | 27,689 | 30,428 |
| **Flying costs** | 77,193 | 120,064 | 126,576 | 132,876 | 290,480 | 146,357 | 218,839 | 368,984 |
| **Other costs** | 52,330 | 65,979 | 62,794 | 65,548 | 126,793 | 71,857 | 101,893 | 162,142 |
| **TOTAL COSTS** | 172,360 | 218,124 | 210,503 | 220,452 | 442,659 | 243,238 | 348,421 | 561,554 |
| **ANNUAL ROUTE COST** | | | | | | | | |
| **Standing costs** | 2,227,545 | 1,668,248 | 1,098,933 | 1,145,453 | 1,320,109 | 1,301,256 | 1,439,829 | 1,582,262 |
| **Flying costs** | 4,014,041 | 6,243,312 | 6,581,967 | 6,909,567 | 15,104,947 | 7,610,559 | 11,379,605 | 19,187,174 |
| **Other costs** | 2,721,138 | 3,430,902 | 3,265,276 | 3,408,495 | 6,593,218 | 3,736,544 | 5,298,452 | 8,431,373 |
| **ANNUAL TOTAL COST** | 8,962,724 | 11,342,462 | 10,946,176 | 11,463,515 | 23,018,275 | 12,648,359 | 18,117,886 | 29,200,808 |
| **ROUTE COST ANALYSIS** | | | | | | | | |
| **Cost per aircraft kilometre** | 4 | 15 | 18 | 19 | 75 | 21 | 39 | 95 |
| **Cost per passenger assuming full capacity** | 291 | 336 | 313 | 306 | 750 | 322 | 455 | 965 |
| **Cost per passenger flying** | 299 | 378 | 365 | 382 | 767 | 422 | 604 | 973 |
| **% increase for flying at capacity** | 3% | 13% | 16% | 25% | 2% | 31% | 33% | 1% |
| **Available seat kilometres** | 90,628,096 | 99,507,200 | 102,875,136 | 110,223,360 | 90,321,920 | 115,734,528 | 117,112,320 | 89,097,216 |
| **Cost per available seat kilometre** | 0.10 | 0.11 | 0.11 | 0.10 | 0.25 | 0.11 | 0.15 | 0.33 |
| **Passenger kilometre** | 88,320,000 | 88,320,000 | 88,320,000 | 88,320,000 | 88,320,000 | 88,320,000 | 88,320,000 | 88,320,000 |
| **Cost per passenger kilometre** | 0.10 | 0.13 | 0.12 | 0.13 | 0.26 | 0.14 | 0.21 | 0.33 |
| **Cost per hour utilised** | 2,670 | 9,974 | 12,797 | 13,661 | 56,472 | 14,700 | 29,302 | 74,096 |
| **SERVICE PERFORMANCE INDICATORS** | | | | | | | | |
| **Weekly aircraft Effeciency (aircraft-km/aircraft)** | 47,104 | 14,720 | 11,776 | 11,776 | 5,888 | 11,776 | 8,832 | 5,888 |
| **Weekly service use intensity (pass/aircraft-km)** | 0.0122 | 0.0392 | 0.0490 | 0.0490 | 0.0980 | 0.0490 | 0.0653 | 0.0980 |
| **Weekly Aircraft fleet Utilisation (aircraft-hrs/aircraft)** | 64.55 | 21.87 | 16.45 | 16.14 | 7.84 | 16.55 | 11.89 | 7.58 |
| **Work utilisation coeffecient (pass/seat)** | 0.97 | 0.89 | 0.86 | 0.80 | 0.98 | 0.76 | 0.75 | 0.99 |

Appendix: V: Node-Hub Calculation Sheet for the 5 mid-point cluster network (Network Cost Model)

Microsoft Excel - midpoint network2.xls

F10 =E10*D10

| | A | B | D | E | F | G | H |
|---|---|---|---|---|---|---|---|
| 1 | **Code** | **Cluster** | **Pass No** | **Cost per pass (US** | **Total costs(US** | **Travel time (hr** | **Pass travel time (pass-hr)** |
| 2 | **ABJ** | WEST | 204,026 | 71 | 14,485,846 | 0.71 | 144,858 |
| 3 | **ACC** | WEST | 177,022 | 83 | 14,692,826 | 1.02 | 179,677 |
| 4 | **ADD** | EAST | 843,027 | 34 | 28,662,918 | 0.77 | 645,969 |
| 5 | **ALG** | NORTH | 1,329,028 | 33 | 43,857,924 | 1.04 | 1,377,205 |
| 6 | **ASM** | EAST | 93,592 | 134 | 12,541,328 | 1.58 | 148,226 |
| 7 | **BGF** | CENTRAL | 84,024 | 108 | 9,074,592 | 0.96 | 80,453 |
| 8 | **BJL** | WEST | 76,643 | 136 | 10,423,448 | 1.51 | 115,444 |
| 9 | **BJM** | EAST | 93,653 | 130 | 12,174,890 | 1.41 | 132,285 |
| 10 | **BKO** | WEST | 114,026 | 76 | 8,665,976 | 0.44 | 50,457 |
| 11 | **BZV** | CENTRAL | 156,022 | 83 | 12,949,826 | 0.79 | 123,842 |
| 12 | **CAI** | NORTH | 1,242,026 | 59 | 73,279,534 | 3.54 | 4,393,667 |
| 13 | **CKY** | WEST | 209,364 | 75 | 15,702,300 | 1.02 | 213,813 |
| 14 | **COO** | WEST | 72,027 | 129 | 9,291,483 | 1.27 | 91,564 |
| 15 | **DAR** | EAST | 135,026 | 108 | 14,582,808 | 1.56 | 210,472 |
| 16 | **DKR** | WEST | 195,022 | 92 | 17,942,024 | 1.68 | 327,393 |
| 27 | **KRT** | EAST | 228,025 | 87 | 19,838,175 | 1.70 | 386,502 |
| 28 | **LAD** | CENTRAL | 132,024 | 106 | 13,994,544 | 1.35 | 177,902 |
| 29 | **LBV** | CENTRAL | 225,026 | 58 | 13,051,508 | 0.45 | 100,980 |
| 30 | **LFW** | WEST | 177,023 | 86 | 15,223,978 | 1.14 | 202,027 |
| 31 | **LLW** | SOUTH | 141,023 | 99 | 13,961,277 | 1.21 | 170,814 |
| 32 | **LUN** | SOUTH | 147,024 | 94 | 13,820,256 | 1.16 | 170,548 |
| 33 | **MGQ** | EAST | 53,695 | 142 | 7,624,690 | 1.27 | 67,924 |
| 34 | **MPM** | SOUTH | 219,023 | 61 | 13,360,403 | 0.48 | 105,952 |
| 35 | **MRU** | SOUTH | 384,022 | 83 | 31,873,826 | 3.20 | 1,229,350 |
| 36 | **MSU** | SOUTH | 99,684 | 118 | 11,762,712 | 1.19 | 118,126 |
| 37 | **NBO** | EAST | 741,025 | 37 | 27,417,925 | 0.74 | 549,285 |
| 38 | **NDJ** | CENTRAL | 65,519 | 149 | 9,762,331 | 1.61 | 105,240 |
| 39 | **NIM** | WEST | 99,674 | 120 | 11,960,880 | 1.24 | 123,596 |
| 40 | **NKC** | NORTH | 66,022 | 195 | 12,874,290 | 2.76 | 182,138 |
| 41 | **NSI** | CENTRAL | 141,029 | 70 | 9,872,030 | 0.43 | 60,466 |
| 42 | **OUA** | WEST | 93,594 | 94 | 8,797,836 | 0.72 | 67,505 |
| 43 | **OXB** | WEST | 65,513 | 137 | 8,975,281 | 1.33 | 86,805 |
| 44 | **ROB** | WEST | 84,264 | 99 | 8,342,136 | 0.77 | 64,673 |
| 45 | **SID** | NORTH | 261,025 | 98 | 25,580,450 | 3.63 | 946,216 |
| 46 | **SSG** | CENTRAL | 155,187 | 78 | 12,104,586 | 0.68 | 105,333 |
| 47 | **TIP** | NORTH | 177,025 | 91 | 16,109,275 | 1.41 | 248,720 |
| 48 | **TMS** | CENTRAL | 30,026 | 169 | 5,074,394 | 0.82 | 24,734 |
| 49 | **TNR** | SOUTH | 636,024 | 53 | 33,709,272 | 1.95 | 1,238,657 |
| 50 | **TUN** | NORTH | 582,023 | 50 | 29,101,150 | 1.42 | 825,018 |
| 51 | **WDH** | SOUTH | 153,023 | 110 | 16,832,530 | 1.99 | 305,090 |
| 52 | **Total** | | | | **977,704,093** | | **26,020,100** |

Xik,Cik,O+D / element I / Hub-Hub cost calculations / **Node-Hub calculations** / Xjl / Ckl / Wjl / element II / total cost

Ready Circular

Appendix: VI: Hub-Hub Calculation Sheet for the 5 mid-point cluster network (Network Cost Model)

Microsoft Excel - midpoint network2.xls

**Passenger numbers**

| | North | South | East | West | Central | |
|---|---|---|---|---|---|---|
| North | 1,755,442 | 1,553,632 | 688,483 | 629,050 | 359,623 | |
| South | 1,553,622 | 2,130,776 | 1,105,830 | 630,557 | 510,898 | |
| East | 688,739 | 1,106,371 | 359,403 | 219,678 | 174,846 | |
| West | 628,739 | 630,207 | 220,462 | 249,645 | 151,237 | |
| Central | 359,630 | 510,909 | 174,779 | 151,319 | 92,250 | |
| | **4,986,172** | **5,931,895** | **2,548,957** | **1,880,249** | **1,288,854** | **16,636,127** |

**Cost per passenger( US$)**

| | | 1 | 2 | 3 | 4 | 5 |
|---|---|---|---|---|---|---|
| | | North | South | East | West | Central |
| 1 | North | 0 | 113 | 79 | 52 | 73 |
| 2 | South | 113 | 0 | 55 | 90 | 68 |
| 3 | East | 79 | 55 | 0 | 108 | 86 |
| 4 | West | 52 | 90 | 108 | 0 | 84 |
| 5 | Central | 73 | 68 | 86 | 84 | 0 |

**Total H-H costs(US$)**

| | North | South | East | West | Central | |
|---|---|---|---|---|---|---|
| North | 0 | 175,560,416 | 54,390,157 | 32,710,600 | 26,252,479 | |
| South | 175,559,286 | 0 | 60,820,650 | 56,750,130 | 34,741,064 | |
| East | 54,410,381 | 60,850,405 | 0 | 23,725,224 | 15,036,756 | |
| West | 32,694,428 | 56,718,630 | 23,809,896 | 0 | 12,703,908 | |
| Central | 26,252,990 | 34,741,812 | 15,030,994 | 12,710,796 | 0 | |
| Total | **288,917,085** | **327,871,263** | **154,051,697** | **125,896,750** | **88,734,207** | **985,471,002** |

**Distance matrix (km)**

| | North | South | East | West | Central |
|---|---|---|---|---|---|
| North | 0 | 6,452 | 4,651 | 2,337 | 3,343 |
| South | 6,452 | 0 | 2,967 | 5,400 | 3,442 |
| East | 4,651 | 2,967 | 0 | 4,767 | 2,664 |
| West | 2,337 | 5,400 | 4,767 | 0 | 2,321 |
| Central | 3,343 | 3,442 | 2,664 | 2,321 | 0 |

**Time(hr)**

| | North | South | East | West | Central |
|---|---|---|---|---|---|
| North | 0.00 | 8.07 | 5.81 | 2.92 | 4.18 |
| South | 8.07 | 0.00 | 3.71 | 6.75 | 4.30 |
| East | 5.81 | 3.71 | 0.00 | 5.96 | 3.33 |
| West | 2.92 | 6.75 | 5.96 | 0.00 | 2.90 |
| Central | 4.18 | 4.30 | 3.33 | 2.90 | 0.00 |

**Passenger travel time expenditure (Pass-hr)**

| | North | South | East | West | Central | Total |
|---|---|---|---|---|---|---|
| North | 0 | **12529961** | 4,004,156 | 1,836,704 | 1,502,804 | 19,873,625 |
| South | 12530042 | 0 | 4,103,253 | 4,253,897 | 2,198,186 | 23,085,379 |
| East | 4002668 | **4101247** | 0 | 1,313,678 | 582,014 | 9,999,607 |
| West | 1837612.3 | **4256259.8** | 1,309,006 | 0 | 439,014 | 7,841,893 |
| Central | 1502774.6 | **2198138.6** | 582,237 | 438,776 | 0 | 4,721,927 |
| | | | | | | 65522430.6 |