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.

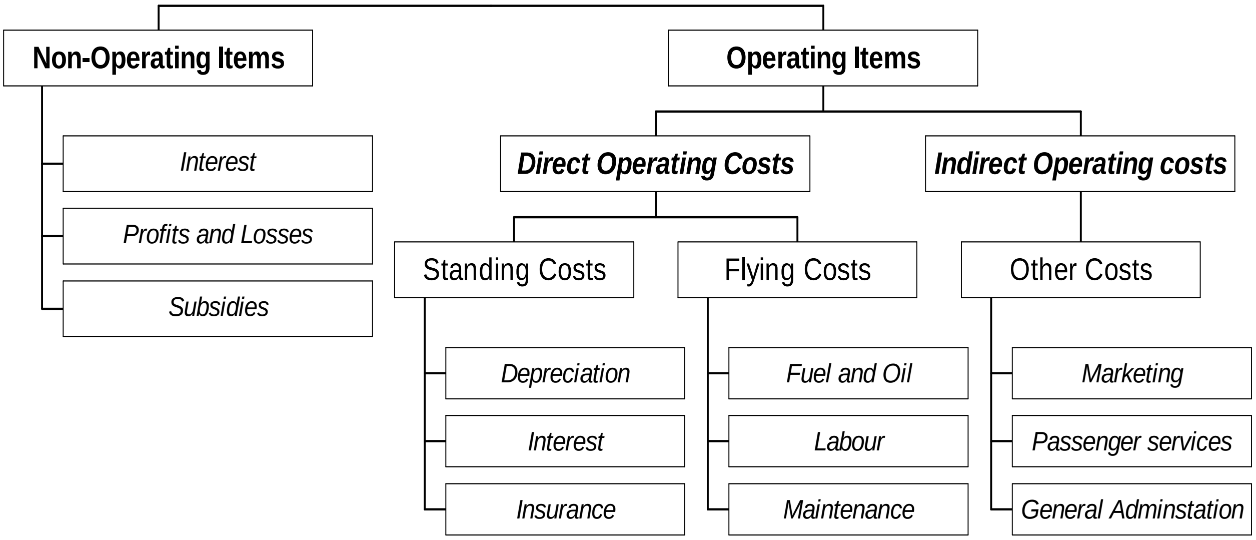


Figure 13: Cost structure adopted for model

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.

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

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*:*

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

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).

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

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.

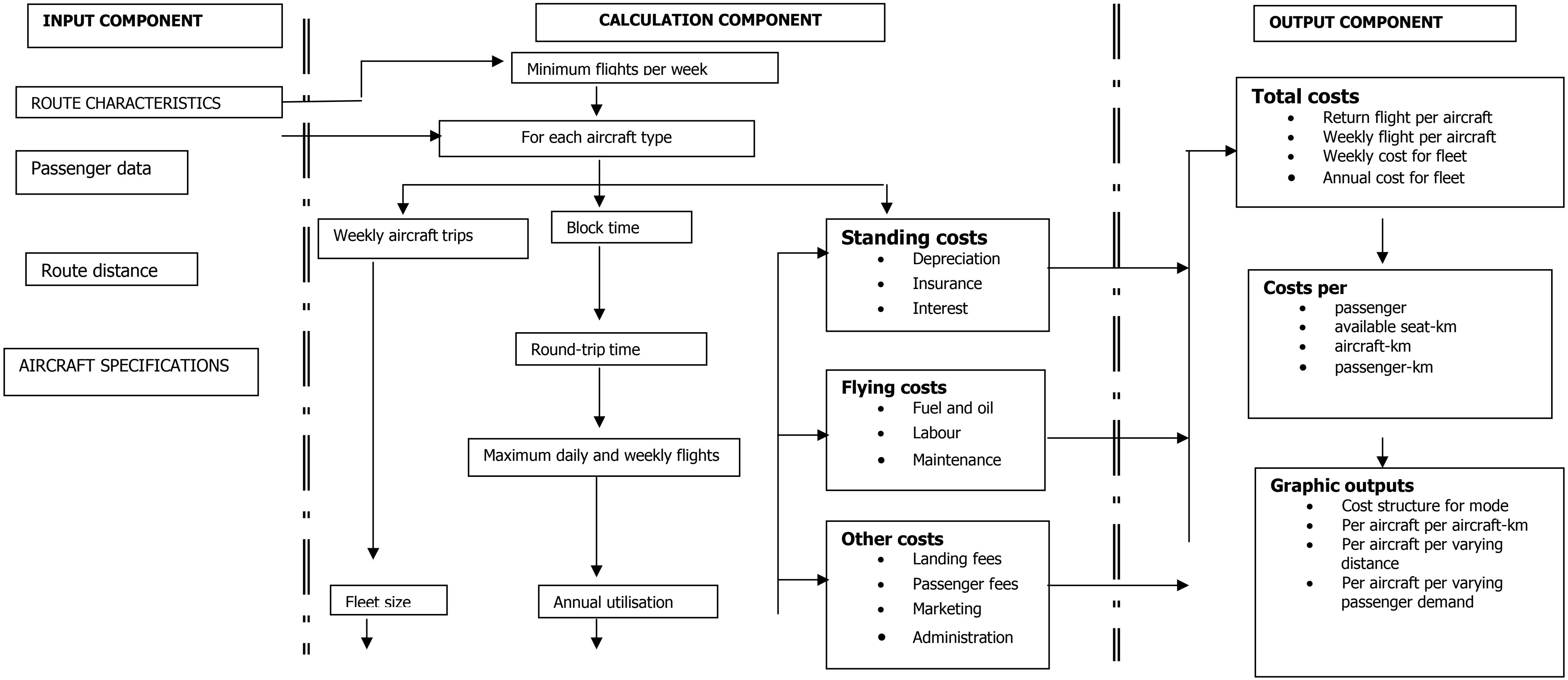


Figure 14: Flow chart of the cost model

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

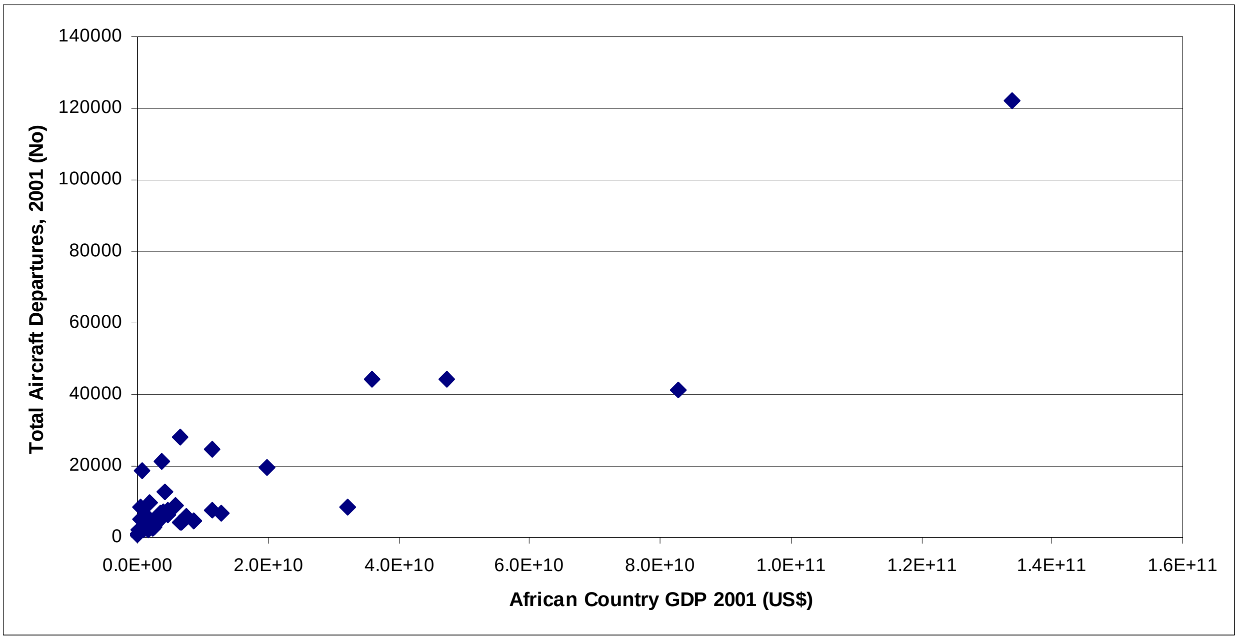
Name of Country	**GDP Per Capita (US$)**	**GDP (US$)**	**Population**	**No. of Annual Aircraft Departures**
Algeria	1 605	47 356 990 000	29 507 000	44 200
Angola	520	6 445 192 000	12 401 580	4 400
Benin	381	2 269 305 000	5 950 330	2 400
Burkina Faso	232	2 485 295 000	10 730 330	3 119
Burundi	134	877 847 300	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.

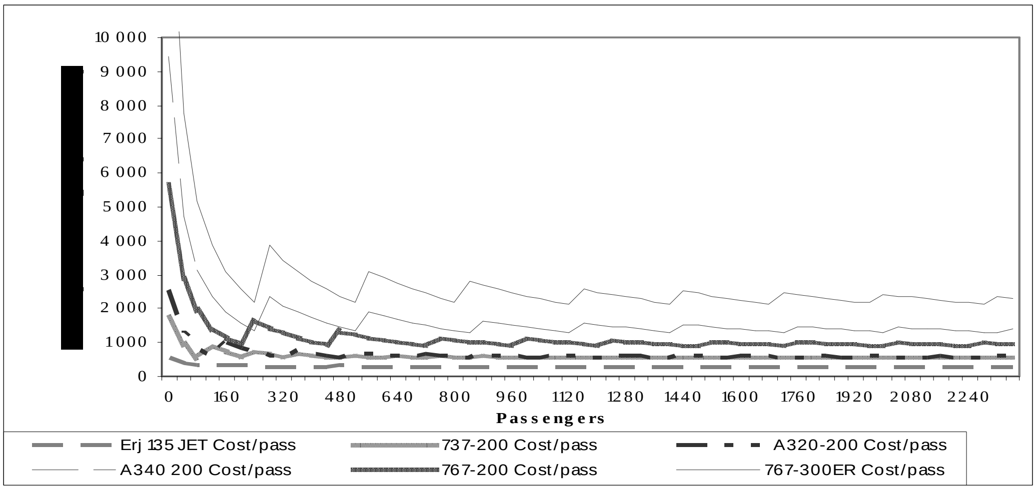


Figure 16: Exponential decrease of costs with increasing number of passengers

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.

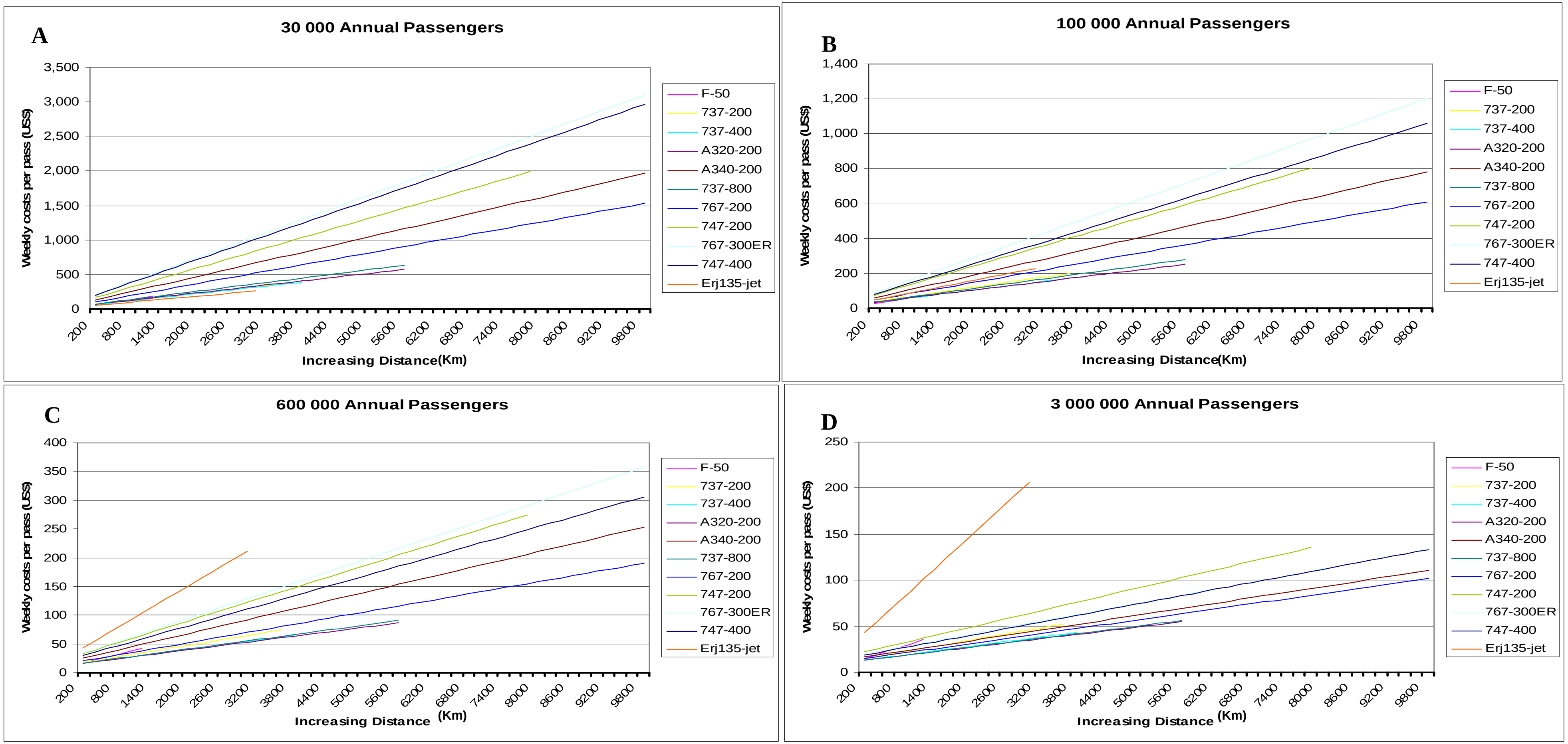
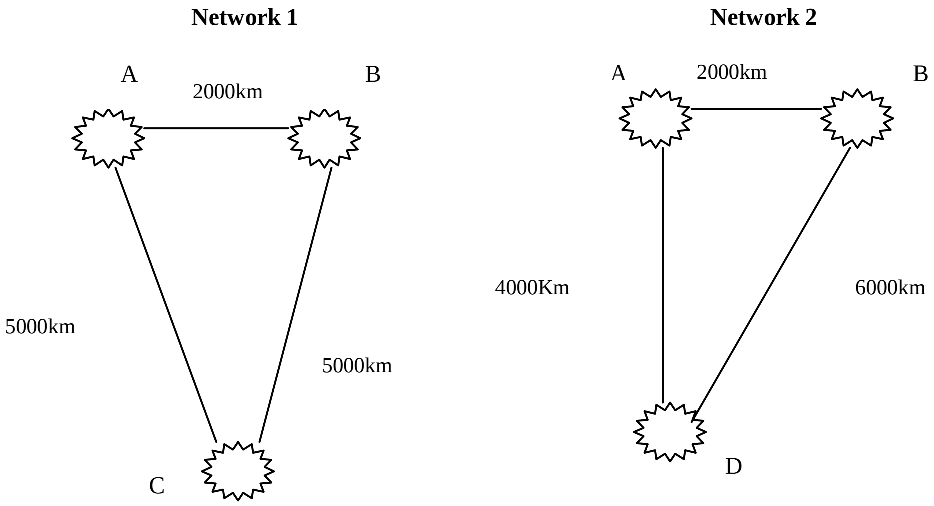


Figure 17: Graphs showing unit costs as distances and passenger numbers increase

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.


Network 1

Network 2

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.