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.

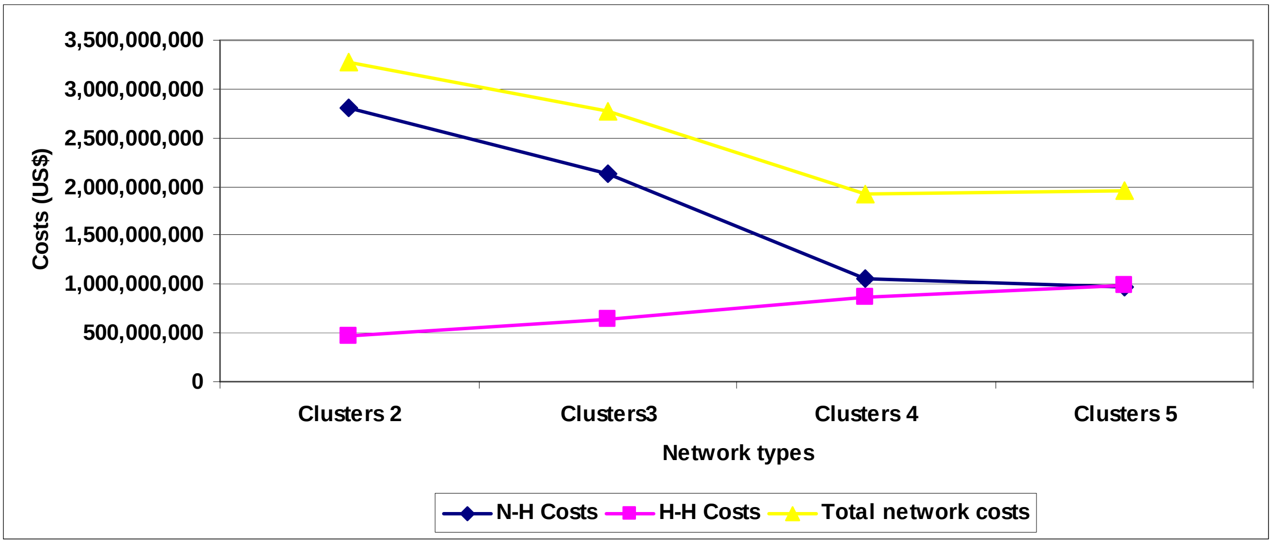

Figure 26: Cost variations as clusters increase in a network

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, α, which represents the value by which costs are discounted on a route when it becomes a hub-hub link. The coefficient α 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.

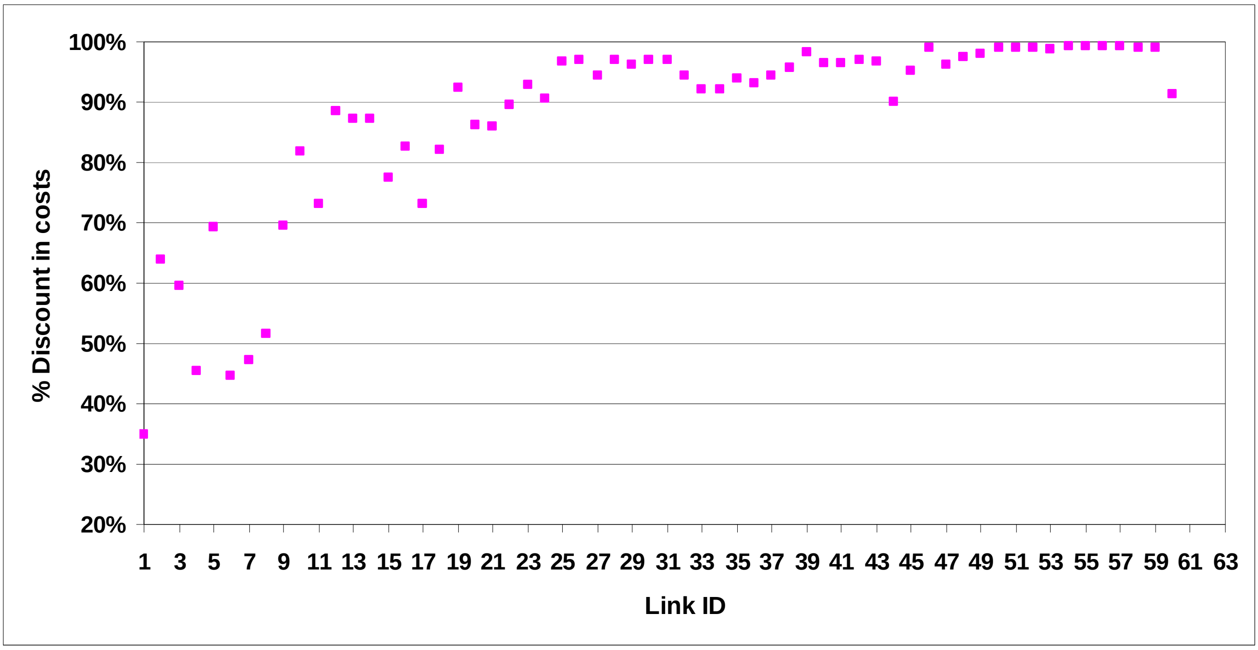

Figure 27: % discount in cost per passenger for various hub-hub links

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.