

## CHAPTER 5: HUB NETWORK DESIGN

### 5.1 Introduction

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

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

### 5.2 Africa Defined as a 'Sparse' Network

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

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

### 5.3 Design Approach

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

#### 5.3.1 Locational analysis

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

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

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

### 5.3.2 Hub airport location

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

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

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

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

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

### 5.3.3 Node allocation

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

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

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

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

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

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

#### 5.3.4 Network costs

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

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

$$f(\mathbf{x}) = \sum_i \sum_k \mathbf{X}_{ik} \mathbf{C}_{ik} (\mathbf{O}_i + \mathbf{D}_i) + \sum_i \sum_k \mathbf{X}_{ik} \sum_k \sum_m \mathbf{X}_{km} \mathbf{C}_{km} \mathbf{W}_{km} \quad \text{Equation 15}$$

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

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

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

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

### 5.3.5 Application of the cost model to design

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

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

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

## 5.4 Hub-location Strategies

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

Some of the methods used to choose and evaluate alternative hub locations involve an advanced form of previously used methods of hub location. In this method the network costing involves the costs of operating an airline service to meet the specific demand as passengers are routed via hubs which should lead to an improved result. However, the need to run the cost model repeatedly imposes a methodological constraint as manual manipulation is required to recalculate the flow and costs for each link in the network design. This

constraint therefore precludes the use of heuristics or the linear programming approaches that have been used in the literature to identify near-optimal H&S network solutions for networks whose demand and cost elasticity variations are known. A future refinement of the present method could involve the automatic recalculation of costs and this could be applied within a programming environment to find the optimal H&S network for Africa considering a large number of alternatives.

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

#### 5.4.1 One-hub network method

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

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

#### 5.4.2 Clustering method

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

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

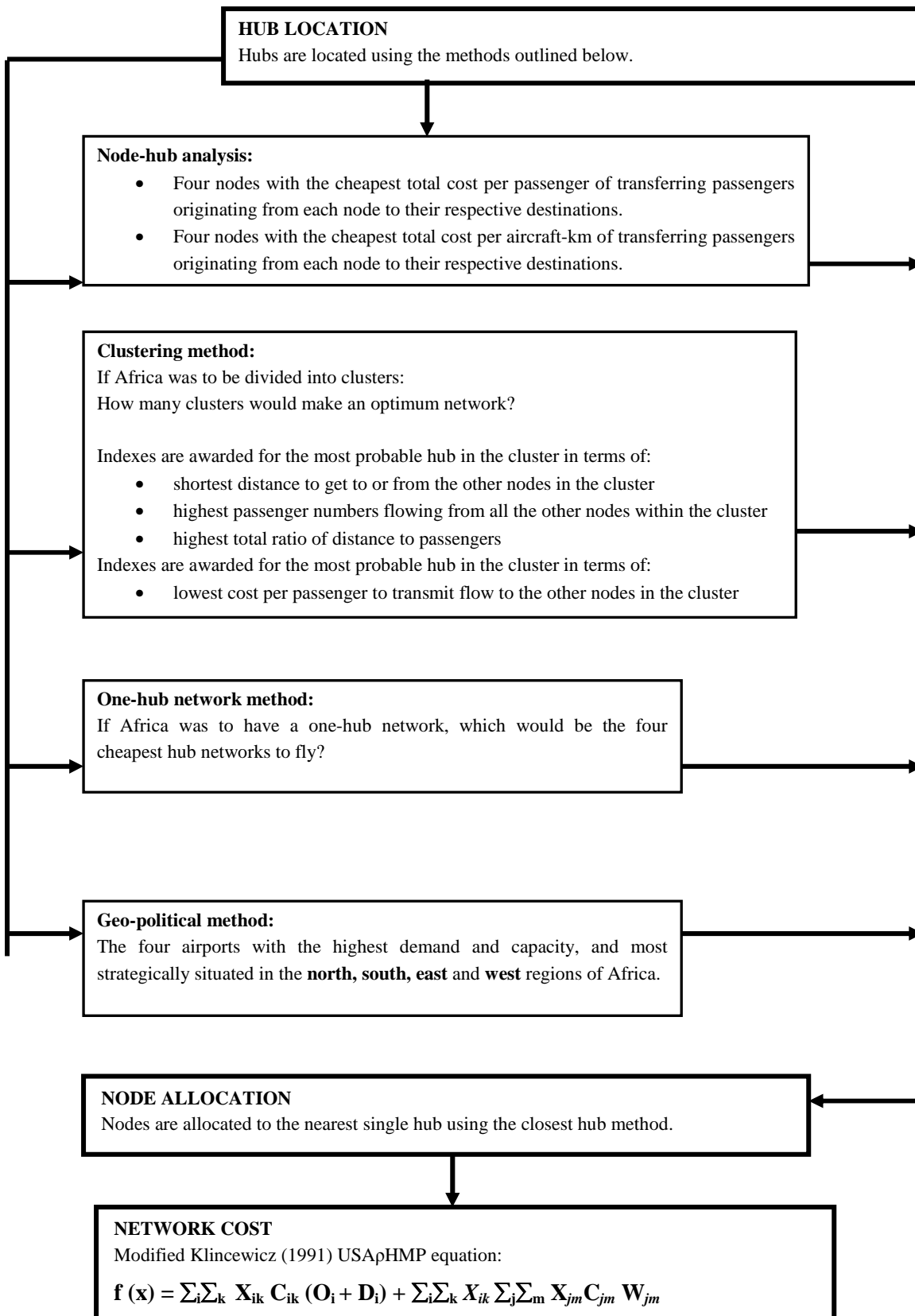


Figure 19: Network design process flow chart

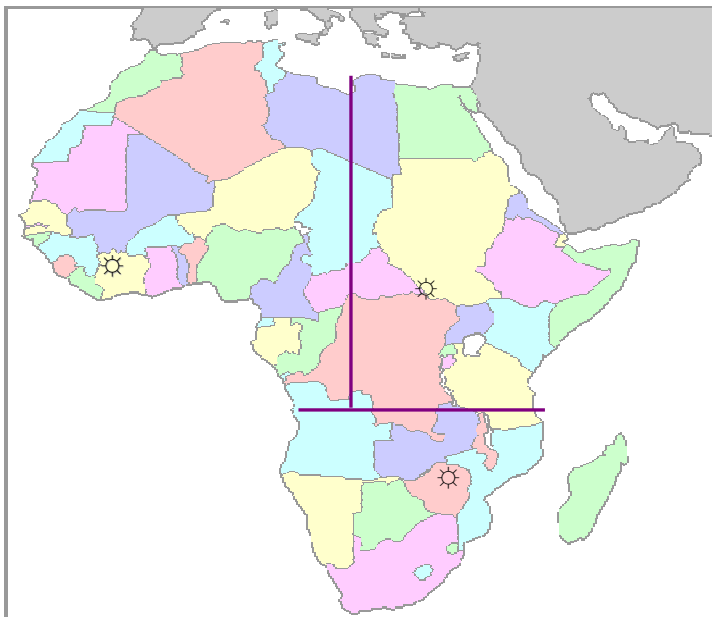
### 5.4.2.1 Optimum number of hubs

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

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

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

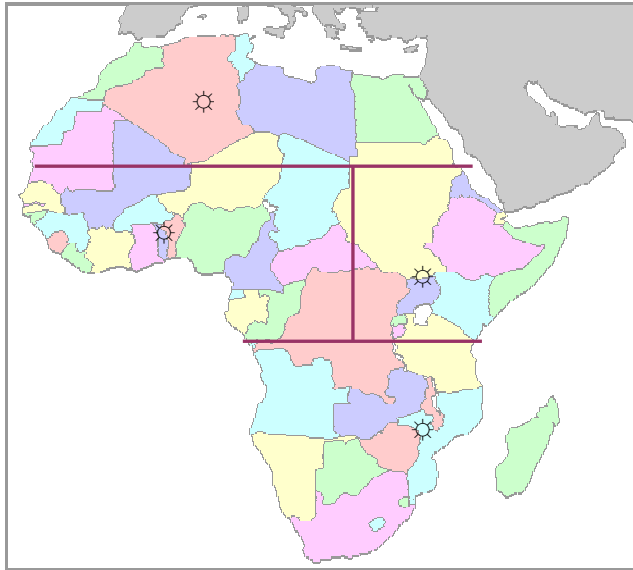
Once the optimum number of hubs has been found for the African region, a more logical procedure that lowers the hub network costs is used to locate the most probable hubs, using their exact locations.



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

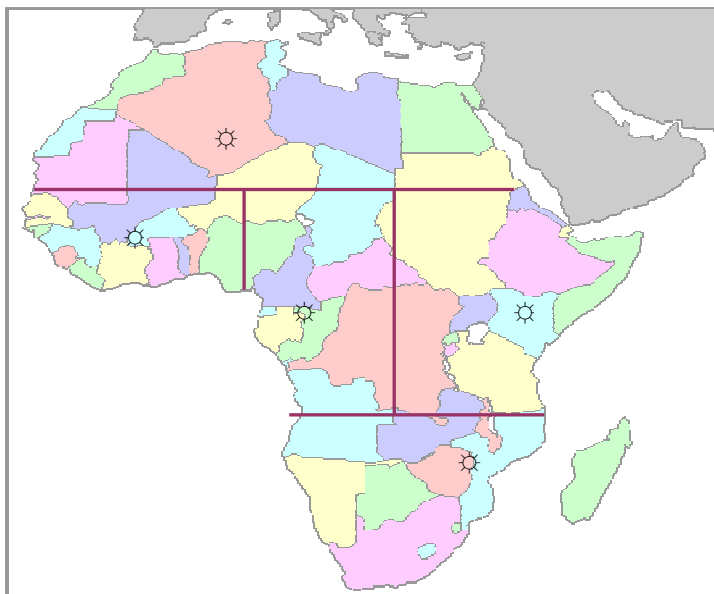
**Figure 20: Three-cluster network**





1. West (ECOWAS)  
Mid-point: 8.14 N      2.74W
2. East (EAC)  
Mid-point: 2.74N      31.40E
3. South (SADC)  
Mid-point: 21.25S      31.21E
4. North (UMA)  
Mid-point: 27,15N      3.65E

**Figure 21: Four-cluster network**



1. West (ECOWAS)  
Mid-point: 9.876      16W
2. East(EAC)  
Mid-point: 3.99N      36.40E
3. South(SADC)  
Mid-point: 22.48S      33.01E
4. Central Economic and Monetary  
Community of Central Africa  
(CEMAC)  
Mid-point: 0.82N      12.65E
5. North (UMA)  
Mid-point: 29.30N      2.02E

**Figure 22: Five-cluster network**

#### 5.4.2.2 Klincewicz's clustering method

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



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

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

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

$$\text{follows: } \frac{140047}{206009} = 0.680$$

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

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

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

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

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

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

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

#### 5.4.2.3 Modified clustering heuristics

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

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

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

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

This procedure is carried out for each cluster for all the  $\rho = 3, 4$  and  $5$  networks and after the hubs from the separate clusters have been chosen, the networks are costed. The advantage of this modification is that it gives the most favourable hub choices, in terms of the costs of moving actual passengers along route distances in these clusters. The rationale for using the two different hub-location methods is to investigate

whether using basic route parameters, such as the distance and passenger numbers shown in Klincewicz’s method, has a greater effect on lowering network costs than using the lowest calculated operating costs.

### 5.4.3 Node-hub analysis

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

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

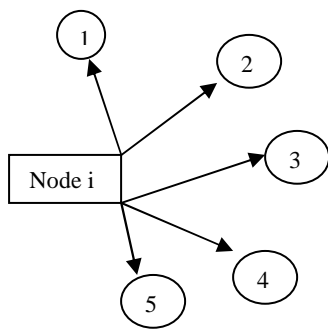


Figure 23 represents the cost of transporting flow “from” each node ( $O_i$ ). The total cost from node  $i$  to each of the  $n$  nodes in the network is summed. The nodes that have the cheapest costs of transporting flow from them are used as hub-location options.

$$O_i = \sum_1^{50} C_{i-n} = C_{i-1} + C_{i-2} + \dots + C_{i-n} + C_{i-50}$$

**Figure 23: The cheapest hub to fly “from”**

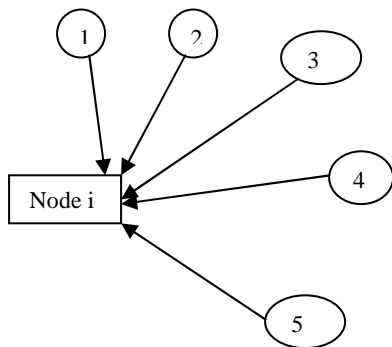


Figure 24 illustrates the calculation of the cost of transporting flow “to” each node ( $D_i$ ). The total costs for all the nodes in the network are summed. The nodes that have the lowest costs to fly to as destinations are used as hub-location options.

$$D_i = \sum_1^{50} C_{n-i} = C_{1-i} + C_{2-i} + \dots + C_{n-i} + C_{50-i}$$

**Figure 24: The cheapest hub to fly “to”**

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

#### 5.4.4 Geo-political method

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

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

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

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

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

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

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

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

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

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

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

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

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

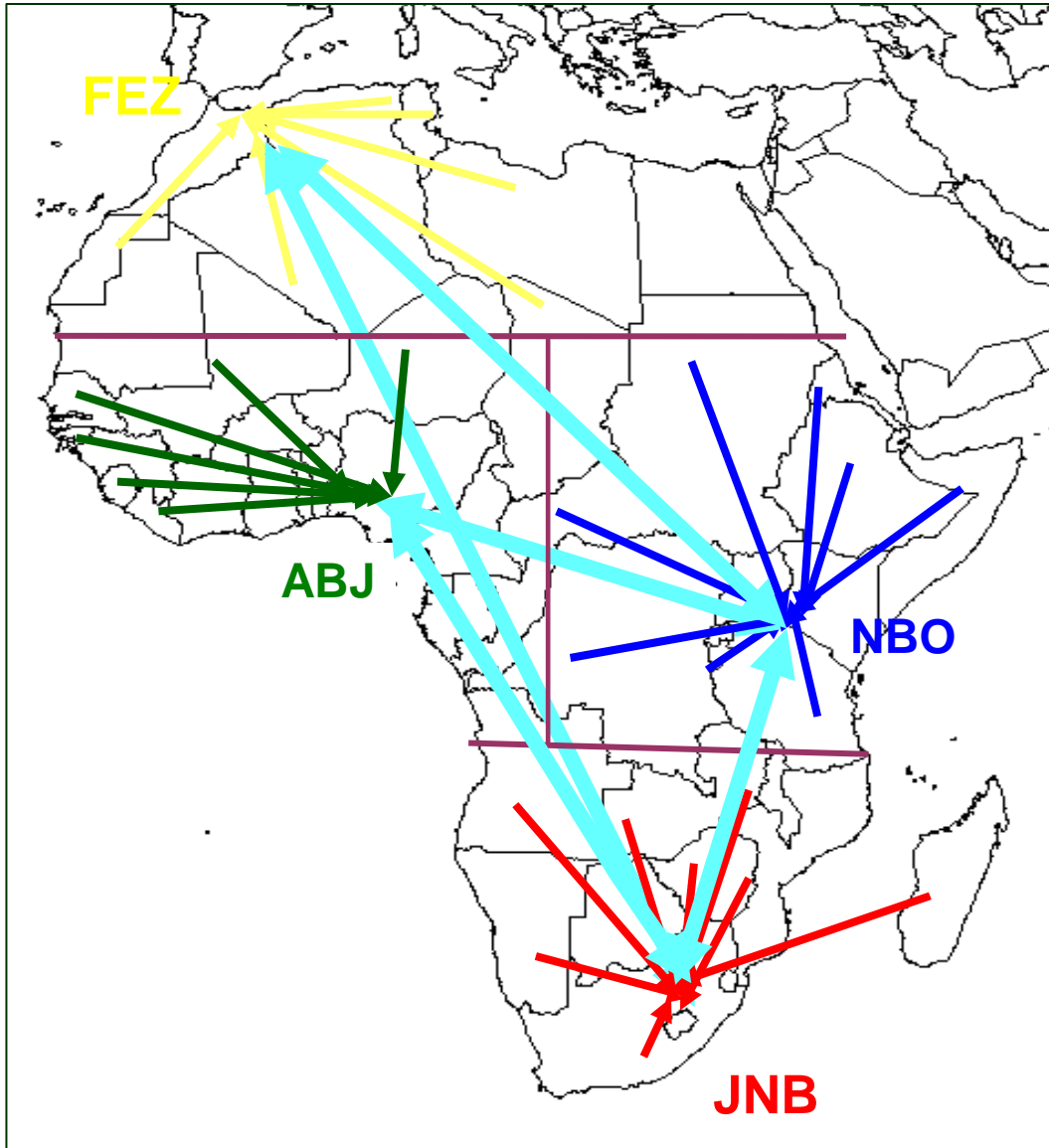


Figure 25: Geo-political network