

Application of Hub-and-spoke Networks in Sparse Markets

The Case of Africa

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Abstract

Hub-and-spoke networks hold promise for decreasing costs and increasing connectivity in air transport markets in countries characterised by sparse demand conditions. This paper examines suitable hub-location and network design methodologies, and the potential evolution of sparse networks over time in Africa. By adopting a cost model to assess the operational effectiveness of alternative networks, we show that low-cost, short-range airplanes have a significant role to play in low-density hub-and-spoke operations. In Africa, a four-hub network centred on high-demand hubs with short node-hub distances is the most suitable option.

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1.0 Introduction

Hub-and-spoke operating strategies are widely applied by airlines to lower costs and gain market advantage. There is significant evidence that consolidation of flows through hub airports can reduce movement costs through economies of scale, even though the distance travelled may increase (Campbell, 1994; Hanlon, 1999). Yet, despite their dominance in many parts of the world, especially in the US and Europe (Button, 2002), hub-and-spoke networks are by no means universal, nor is there agreement about their benefits (Hanlon, 1999; Schnell and Huschelrath, 2004).

Given that most of the experience with hub-and-spoke (H&S) strategies is from the more developed parts of the world, it is worth asking whether similar results can be obtained under different circumstances, and how the benefits would compare with the disbenefits. Airlines in developing regions tend to operate in sparser markets where traffic densities are much lower and distances are often greater than in traditional H&S markets.

Previous analyses of hubbing in sparse markets have focused on single countries with short sector distances (Saudi Arabia; Abdulaziz, 1994) or small regions (South-East Asia; Bowen, 2000). The continent of Africa is probably the most extreme example of the complexities attendant on the sparse and underdeveloped airline market. Can airline-based hub networks be migrated to a carrier-independent H&S network that would benefit more users and support economic development in Africa? What would a suitable H&S network in Africa look like?

The paper examines these questions in the context of African conditions, first to give an indication of a potentially desirable trajectory for the development of continental aviation. The findings also shed light on the suitability of H&S operations in sparse markets in general, and the specific constraints imposed on the design of an optimal network under conditions of sparsity. An innovative approach is taken which uses an engineering cost model developed by the authors to estimate the costs of operating an airline route in order to find an optimal combination of aircraft type and frequency for a given sector distance and load. The economies of scale resulting from H&S operations are therefore estimated directly, rather than from an econometric cost function estimated from airline data as is the usual practice. The approach is similar to but independent of work recently undertaken by Swan and Adler (2006) in the US, but is applied to the hitherto unstudied African context. The paper also applies and compares various practical methods for designing an H&S network, and identifies promising methodologies that are consistent with the scarcity of data in emerging markets by relying on approximate methods rather than data and computationally intensive optimisation exercises.

The focus is strategic — in other words it is on the implications for passengers (in terms of travel times and frequencies) and airlines (in terms of operating costs) of moving towards an H&S network. Issues of competition and fare policy are not considered explicitly, nor is intercontinental connectivity, as the focus is on intra-continental air travel.

The paper starts with a brief discussion of aviation in Africa and issues affecting sparse airline networks in general. A description of the hub network design methodology and the cost model approach and input data used follows. The results of various design methodologies are compared, and, lastly, conclusions are drawn on the Africa-specific and general outcomes of the research.

2.0 Context: Aviation in Africa

2.1 Africa as a sparse market

Africa is a large continent of 30 million km², with dimensions three times the size of Europe and distances from the south to the north of about 8,000 km. Africa's population is over 860 million — 13 per cent of the world's total — but in 2004 air passenger traffic contributed only 4.1 per cent to the world total (Chingosho, 2005). This makes it the smallest region for air services worldwide. The annual number of air trips per inhabitant in Africa is only 0.14, as compared with Europe (1.37 trips) and North America (4.13 trips) (Chingosho, 2005).

The African aviation industry clearly displays the symptoms of thin transport markets as air fares tend to be much higher than those found in other regions of the world (Chingosho, 2005). Furthermore, the elasticity of demand with respect to fares for African travellers is the lowest in the world, at -0.64 , compared with -0.69 in Latin America — next lowest — and -2.95 in the US (Chingosho, 2005).

Service frequencies tend to be low in thin markets (Pels *et al.*, 2000), as are load factors. Table 1 illustrates how low the traffic densities are for 276 city pairs in west and central Africa (UNECA, 2006) — 35 per cent of the 276 city pairs have fewer than ten passengers per day per direction.

Figure 1 shows data for different regions of the world on airline load factors, defined as the ratio of the revenue passenger kilometres (RPK) to the available seat kilometres (ASK). Airline load factor is a critical determinant of profitability. At an average of 62 per cent, African routes have the lowest load factor in the world.

Sparse markets are not necessarily uniformly thin, but can be dominated by a few very strong nodes. In Africa's case, this dominance comes from five countries: South Africa, Nigeria, Egypt, Morocco, and Algeria together account for 67 per cent of the continent's combined Gross Domestic Product (GDP) and 43 per cent of its air travel (World Bank, 2003).

2.2 African aviation issues

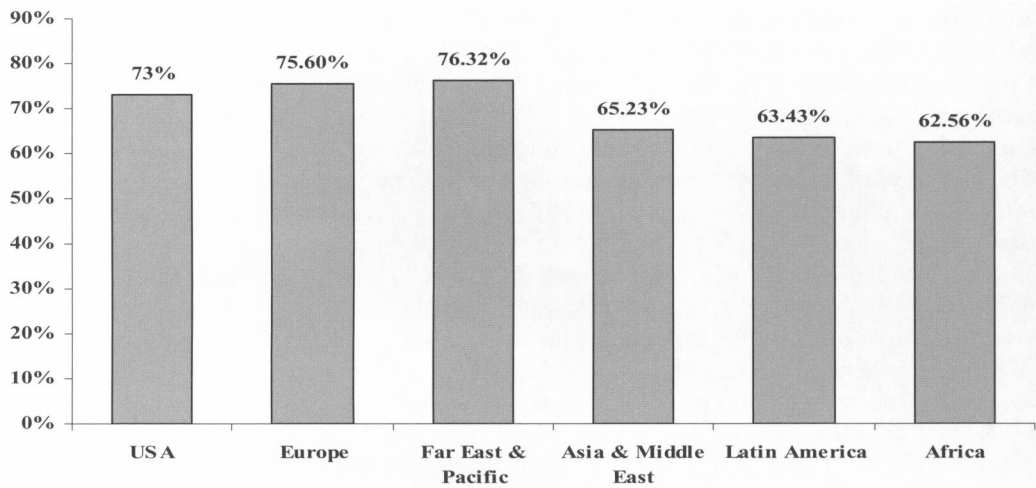
Supply conditions in African aviation are characterised by fragmentation, protectionism and technical challenges. Salient issues in the institutional, technical, and operational areas are as follows:

Table 1
Passenger Demand for 276 City Pairs in West and Central Africa

<i>Traffic per day and per direction</i>	<i>City pairs</i>	<i>Per cent</i>
>150 passengers	14	5
70–150 passengers	28	10
30–70 passengers	69	25
10–30 passengers	69	25
<10 passengers	96	35
Total	276	100

Source: UNECA, 2006.

Figure 1
Average Load Factors for World Regions



Source: Chingosho, 2005.

- There is criticism of Africa's civil incoherent air transport policies, excessive bureaucracy, and bad management strategies (Akpoghomeh, 1999).
- Many airport authorities and operators are struggling to maintain the technical standards required by the International Civil Aviation Organization (ICAO), with 89 per cent of the EU-blacklisted airlines originating from the region.
- In terms of infrastructure, the facilities at most African airports are hugely insufficient in the light of technological advances and the heightened security demands imposed on the industry (Kuuchi, 2007).

It would appear that consolidation and liberalisation of the African air transport industry is the only way to improve economies of scale, and develop the market on the continent through consolidation of airlines into four or five strong regional operators (Morrison, 2004). A better understanding is therefore needed of how a consolidated and rationalised route network — such as a hub-and-spoke network — might contribute to improving economies of scale and service quality.

3.0 Hub Network Design Methodology

This paper applies various operations research methodologies to design cost-effective hub-and-spoke (H&S) networks, which are then compared. This paper uses various hub-location strategies and applies an H&S network cost methodology to determine the most efficient H&S network. Generally, a pure hubbing strategy is followed, whereby all flow from/to a node airport is routed through its hub (O'Kelly and Bryan, 1998). The single-assignment model is used in the methodology, where a node can only flow to a single hub. According to O'Kelly *et al.* (1996), the use of a single assignment may be seen as a

special case of the more general multiple-assignment model, since the optimal solution to a multiple-assignment model may result in single allocations for all nodes. Hubs therefore serve as collection, transfer, and distribution points. No direct flights are allowed between nodes that are not hubs. This may be appropriate for sparse networks as previous research has shown that the optimal number of direct links in an H&S network increases as the demand grows (Jaillet *et al.*, 1996). To be able to examine clearly the economic benefits of pursuing operational optimality in network design, it is assumed that no regulatory restrictions apply as to which airports may be linked (an example being that Fifth Freedom rights are granted).

In accordance with the standard H&S design method, the problem breaks down into two interrelated steps: a hub-location step in which airports are chosen to act as hubs; and an allocation step in which nodes are allocated to hubs. The methods used are now briefly described.

3.1 Hub location

An attempt was made to widen the set of potential hub locations by ignoring all factors related to the present capacity and state of the airports. The aim was to derive a first-order sense of what a near-optimal H&S network might look like in the African context based solely on operating cost criteria, which are determined only by an airport's demand and location characteristics. The hub-location methodologies tested are:

- a one-hub network method based on the hub with the single lowest cost;
- two-, three-, and four-hub networks in which hubs are chosen using a heuristic clustering methodology developed by Klinecicz (1991);
- two-, three- and four-hub networks in which hubs are chosen using a clustering methodology based directly on airline route costs.

3.2 Node allocation

The allocation of nodes to hubs is essentially done during a clustering step, when nodes are clustered together according to criteria described below. Once cluster boundaries have been defined and hubs have been chosen, nodes are allocated to a single hub within the cluster. This implies that flow will always go through either one or two hubs, depending on the destination. Hub airports are fully interconnected. The movement in the network thus falls into the following general categories: node–hub–node (N–H–N); hub–node (H–N or N–H); hub–hub (H–H); and node–hub–hub–node (N–H–H–N).

3.3 Network costs

The performance of each candidate H&S network is assessed partly on the total network cost of transporting all passengers from their origins to their destinations through the hubs. The costs are calculated as a product of the costs per unit flow and the flow along all the routes. Mathematically, the total costs can be expressed using equation (1), as developed by O'Kelly (1987) for solving the Uncapacitated Single Allocation p -hub Median Problem (USApHMP), and rewritten by Klinecicz (1991), but adapted for this work where i = node, and k and m are hubs within a network:

$$f(x) = \sum_i \sum_k X_{ik} C_{ik} (O_i + D_i) + \sum_i \sum_k X_{ik} \sum_k \sum_m X_{km} C_{km} W_{km}. \quad (1)$$

The first term in equation (1) calculates the collection and distribution costs (node–hub movement), and includes the following:

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

The second term in equation (1) calculates the cost of moving passengers through the hubs k and m as follows:

- W_{km} represents the passenger demand on a hub–hub route.
- The factor X_{ik} is represented as 1 if that node–hub movement occurred before the hub–hub movement and as 0 otherwise.
- The factor X_{km} is represented as 1 if the hub–hub movement occurs for a given origin–destination (O–D) path and as 0 otherwise.
- C_{km} represents the cost per passenger on the H–H links from hub k to hub m .

In most previous applications of equation (1) (O’Kelly, 1987; Klinecicz, 1991), the costs per passenger (C_{ik} and C_{km}) were estimated from econometric cost functions based on data reported by US airlines. The hub–hub costs are typically multiplied by a discount factor, α , which represents the discount on fares due to economies of scale when a link becomes an H–H link. O’Kelly and Bryan (1998) investigated the practice of applying a constant value for α that is exogenously determined — typically in the region of 0.75 — and found that it does not adequately capture the relationship between costs and flows on hub–hub links.

The approach adopted here uses an engineering cost model which calculates the lowest cost at which a particular segment can be served, by selecting an appropriate aircraft type and frequency for the given sector length and passenger demand. It therefore automatically recalculates the lower cost, C_{km} , when a link becomes an H–H link, without relying on an assumed discount factor. The use of this engineering cost model is particularly important in a sparse market where demand numbers and service supply costs vary significantly between routes. The assumption of a discount factor would not be representative of the sensitivity of costs in the African market as passenger numbers increase on routes.

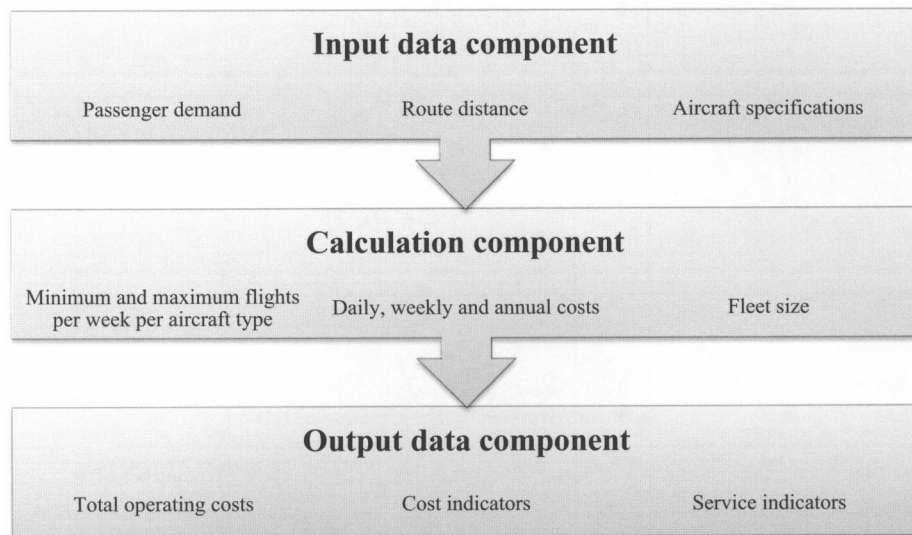
3.4 Description of engineering cost model

The cost model used to estimate the costs per passenger, C_{ik} and C_{km} , was developed by Ssamula (2004) using Africa-specific data. The model calculates the operating costs and service parameters such as aircraft utilisation for aircraft typically used in African air transport.

Figure 2 illustrates the structure and data components of the model. The model and input data sources are described in more detail in Ssamula *et al.* (2006). Important properties and assumptions are as follows:

1. The model accounts for all costs an operator incurs in running an air transport service.

Figure 2
Schematic Diagram of Cost Model



2. The intensity with which an aircraft is used on a route is limited by both minimum and maximum flight frequencies. A minimum frequency at which each node has to be served to provide a minimum level of service regardless of passenger numbers is specified by the user — this is taken as one flight per week, reflecting the low demand extant in many African origin–destination (O–D) markets. The maximum frequency is determined by the usable hours per day, and the aircraft block time and servicing time.
3. The capital cost component assumes that when an aircraft is not flying, it is to be leased out or used for different routes. Utilisation-linked capital costs are appropriate as many routes in sparse networks may have low frequencies, in which case individual aircraft will be used on several routes over the course of an operating week.

3.4.1 Input data

The cost model considers eleven potential types of aircraft, as shown in Table 2. They consist of short-, medium-, and long-range aircraft commonly used by airlines within Africa. Aircraft data were obtained from the Airclaims CASE Database (2000).

Each of the fifty countries in Africa is represented by one major international airport whose traffic and passenger demand is the highest, for countries that have more than one airport. Demand data had to be compiled at the country level from available sources, as no single database of intercontinental O–D pairs of transport demand exists. The following procedure was adopted.

World Bank Data Query, an online database for World Bank member countries, provided data on GDP (in US\$) and aircraft departures per year for 2001. The average number of departures and arrivals regionally to and from destinations within Africa is given by the African Airlines Association (AFRAA, 2000) as 15 per cent of the total passenger traffic. Intercontinental traffic is excluded from the demand calculations, as the

Table 2
Technical Specifications for Model Aircraft Types

Specifications	Embraer Erj 135 JET	Fokker F 50	Boeing 737-200	Boeing 737-400	Boeing A320-200	Boeing A340 200	Boeing 737-800	Boeing 767-200	Boeing 747-200	Boeing 747-300	Boeing 747-400
Cruising speed	833	448	760	815	833	861	810	850	895	897	914
Passenger capacity	37	56	130	168	180	295	189	255	291	411	401
ToGWmax	21,100	19,950	52,437	68,040	73,500	27,500	78,240	136,080	374,850	377,800	390,100
Max. fuel capacity (gallons)	5,187	1,357	5,163	5,701	6,300	36,984	6,878	24,179	53,858	53,858	57,284
Engine type	AE3007	PW125B	JT8D-7	CFM 56-3B1	V2500-A1	CFM56-5C2	CFM56-7B20	RB211-524H	RB211-524D4	Trent 600	RB211-524H
Thrust (lbf)	7,400	5,000	14,000	20,000	25,000	31,200	21,000	59,500	53,000	68,000	59,500
Cruise SFC (lb/lbf h)	0.36	0.32	0.585	0.38	0.35	0.32	0.38	0.373	0.373	0.45	0.373
Maximum range	3,019	1,300	3,700	3,810	5,615	13,500	5,670	12,250	7,900	7,700	13,480
Number of engines	2	2	2	2	2	4	2	2	4	4	4
Number of crew	5	5	6	7	7	8	7	7	8	8	8

paper focuses on creating a hub network only for air passenger traffic within Africa. However, the African node–hub portions of the intercontinental trips is automatically included in the passenger demand.

To convert aircraft departures into passengers, an average seat capacity is calculated for the aircraft types used in the model (Table 2). This comes to about 200 seats, which is multiplied by the average load factor for African airlines of 62.6 per cent (Chingosho, 2005) to arrive at the estimated trips generated in each country.

A doubly constrained gravity model with a suitable deterrence function is used to estimate an O–D passenger matrix for the 50×50 O–D pairs on the continent. The distance matrix was determined from straight-line distances between airports. The O–D matrix was not formally validated because of the lack of available and reliable city-pair data, but it is adequate for this strategic-level analysis. The operating cost model drives both the design and the assessment of alternative H&S strategies.

4.0 Hub Location Strategies and Results

The alternative H&S networks considered in this study are differentiated solely by the strategy adopted in identifying the hubs. The strategies attempt to elucidate strategic issues needed for airlines to improve network form and performance from an operating cost perspective, for the particular conditions of Africa. Methodologically, much research has been conducted on optimal strategies for designing H&S networks, using operations research methods such as linear programming (Campbell, 1994), and various heuristic algorithms described by O’Kelly and Bryan (1998) and, more recently, by Topcuoglu *et al.* (2005). This work has by and large shown that small networks (of up to about twenty-five nodes) can be solved to optimality, but that heuristic methods are needed for solving larger networks (Klincewicz, 1991). The results of the various hub network costs are summarised in Table 3 on page 291.

4.1 One-hub network method

As a starting point, each node is analysed as a hub option in a one-hub network ($p = 1$) of $n = 50$ nodes. This approach is not realistic as it requires extremely long, circuitous routes that would not be acceptable in terms of travel time. However, the total networks from this method are the lowest of all alternatives as it eliminates the hub–hub portion entirely. The best location for a single hub is TMS (Sao Tome and Principe), which is located in central Africa.

4.2 Clustering methods

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 $p = 1$ network to locate the most probable hub using a defined set of rules. The cluster method was used to investigate:

- the optimum number of hubs for the African network;
- the optimum location of hubs in clusters using the following two methods:

- the Klincewicz (1991) method of hub location, in which the probability of a node becoming a hub in a cluster is based on its rank in terms of node–hub distances and passenger numbers;
- a modification to the Klincewicz clustering method, in which the probability of a node becoming a hub in a cluster is based on its node–hub operating costs, as derived from the cost model.

It was decided to choose cluster boundaries using a pragmatic approach rather than a strictly rule-based one. The approach involved demarcating cluster boundaries on the basis of Regional Economic Communities (RECs) in the major areas in the north, south-east, and west of Africa. The advantage of using the RECs is that they are already accustomed to some measure of regulatory and institutional cooperation. The four main RECs that are potential clusters are:

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

Sensitivity testing of the cluster boundaries was performed by reassigning airports close to the boundaries to an adjacent cluster if that reduced the distance to the hub (Ssamula, 2008), to test whether the performance of the network changed if the boundaries shifted and the hub airport was changed. The results showed that the network performance was not very sensitive to the exact location of the boundaries, no doubt because (in the case of Africa) the nodes near the boundaries are low-volume airports contributing very little to overall costs.

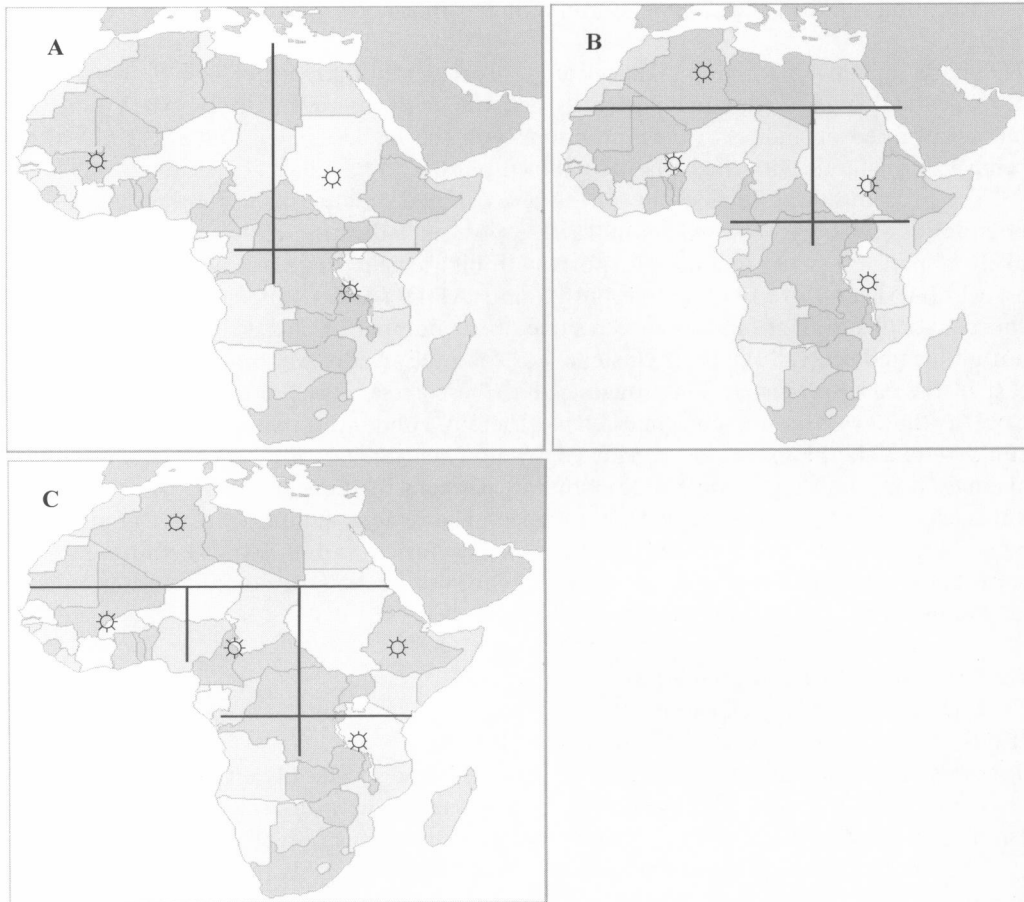
4.2.1 Optimum number of hubs based on mid-point analysis

Several researchers, such as Jaillet *et al.* (1996) have found that hubs tend to be located in the centre of the regions they serve. This principle was applied in an effort to find the appropriate number of clusters or hubs for Africa, without having to designate any specific airport as the hub. A procedure performed by Topcuoglu *et al.* (2005) was used which involved finding the geographical location of the mid-point in each cluster using the latitude and longitude of all nodes in the cluster. Instead of then choosing the node that was nearest to the mid-point to act as a hub, we used the geographical mid-point as a ‘virtual’ hub through which all cluster traffic is routed.

The method was applied by testing two-, three-, four- and five-cluster networks in Africa. Figure 3 shows the cluster divisions, the RECs in that geographical region, and the virtual hub locations for the three-, four-, and five-cluster networks respectively.

The results in Table 3 show that, as expected, the aggregate hub–hub costs increase as the number of clusters increases. The higher the number of clusters/hubs, the higher the overall hub–hub flow. However, this flow gets distributed across more hub–hub links with longer distances, resulting in higher costs. The higher hub–hub costs are more than offset, however, by the node–hub costs which decrease as clusters shrink. In total, the four-cluster network performs best, although the five-cluster network, which looks very

Figure 3
Three-, Four- and Five-cluster Network Boundaries and Hypothetical Hubs



similar geographically (Figure 3B and C), performs almost as well. Aggregate passenger travel times reduce as the number of clusters grows because the amount of circuitry between node airports is reduced. Thus the five-cluster network has the lowest overall travel time. (Note that the travel time in Table 3 excludes transfer time.) We conclude that either a four- or a five-hub network, with clusters drawn around the boundaries, may be appropriate for the present African market.

Now that an appropriate number of hubs has been found for the African region, a more systematic procedure is used to locate the most probable hubs using their exact locations.

4.2.2 *Klincewicz's clustering method*

Klincewicz (1991) describes a heuristic method for locating the most attractive hub in a cluster by scoring all nodes according to two criteria:

1. The aggregate node–hub distances that would be travelled if that node were to be the single hub.
2. The total number of passengers originating at that node.

The basis of this method is Klinkewicz's observation that airports with both short distances and high originating passenger demand perform well as hubs. Each potential hub is awarded an index for each criterion, with the highest index that can be awarded being 1.0. The node with the highest combined score within a cluster is chosen as the hub.

The procedure was carried out for the $p = 3, 4,$ and 5 networks using the same cluster boundaries as before. The results in Table 3 give an indication as to which airports are likely to perform better as hubs. Airports with high originating passenger numbers, such as ALG (Algiers), JNB (Johannesburg), and ADD (Addis Ababa), are consistently chosen as hubs in their clusters, irrespective of the number of clusters. These airports are not all located centrally in their clusters. For example, Addis Ababa is located far to the east in the eastern cluster. This suggests that the cost savings accrued by locating hubs close to the few large regional markets — thereby eliminating many node–hub trips — could outweigh the extra costs incurred by non-central locations within a cluster. On average, node–hub costs contribute about 58 per cent to the total costs, while the hub–hub costs contribute only 42 per cent, reflecting previous findings on the relationship between node–hub and hub–hub costs (O'Kelly and Bryan, 1998). The rationale for connecting the nodes to the hubs, over the shortest possible distance, in order to take advantage of the lower hub–hub costs, is strong.

4.2.3 Modified clustering heuristics

This method modifies Klinkewicz's (1991) heuristic clustering method by changing the criteria for choosing the hub, from one based on the best combination of node–hub distances and originating passenger demand to one based specifically on the node–hub costs associated with the hub. The motivation is that the engineering cost model allows us to estimate the costs of transporting all node–hub passengers to a potential hub in a cluster.

The results (Table 3) show that this modified procedure leads to hub choices that are in some cases different from what would be found using Klinkewicz's original method. While the major airports of Johannesburg (JBG) and Addis Ababa (ADD) still tend to perform best as hubs in their respective clusters, the hubs in other clusters shift from one major airport to another in an effort to reduce node–hub costs. Interestingly, this procedure raises the hub–hub costs for the $p = 3, 4,$ and 5 networks, purely as a result of changes in hub–hub distances. The hub–hub passenger volumes are the same as in the first case, but the repositioning of hubs increases total hub–hub distances and raises hub–hub costs.

Overall, the modified clustering method does not result in consistently lower network costs (Table 3). Seeking optimality *within* predefined clusters does not guarantee optimality *between* clusters, but the difference is relatively small (no greater than 3 per cent) compared with Klinkewicz's method. However, the modified method results in much lower aggregate travel times in all networks — in the order of 18 per cent less than in Klinkewicz's method. Evidently, the engineering cost approach leads to solutions that favour high-demand airports as hubs to such an extent that significant numbers of node–hub links are eliminated to the benefit of passengers originating at these airports.

Table 3
Summary of Different Hub Network Costs

No.	Network types	Node-hub costs (US\$)	Hub-hub costs (US\$)	Total costs (US\$)	Percentage variation from cheapest network	Total pass. travel time expenditure (pass-h)
1	Geopolitical	851,005,541	724,350,402	1,575,355,943	0.00	112,084,885
2	One-hub network	1,521,300,419	0	1,521,300,419	-3.43	141,732,732
3	Two-cluster network	2,808,954,950	470,214,725	3,279,169,675	108	149,495,864
4	Three-cluster network	2,129,156,696	637,616,805	2,766,773,501	75.63	117,869,225
4	Four-cluster network	1,049,102,631	867,861,904	1,916,964,535	21.68	120,77,306
6	Five-cluster network	977,704,093	985,471,002	1,963,175,095	24.62	108,523,760
CLUSTERS 5						
7	Klincewicz's method	814,102,323	1,060,831,867	1,874,934,184	19.02	111,331,865
8	Modified clustering method	770,627,166	1,076,267,842	1,846,895,008	17.24	92,838,440
CLUSTERS 4						
9	Klincewicz's method	859,974,307	992,701,815	1,852,676,122	17.60	115,690,086
10	Modified clustering method	833,740,441	1,023,900,295	1,857,640,736	17.92	96,344,797
CLUSTERS 3						
11	Klincewicz's method	1,067,998,046	822,383,914	1,890,381,960	20.00	140,508,228
12	Modified clustering method	1,022,158,662	927,117,792	1,949,276,454	23.74	107,761,707

The modified method seems to lead to networks that are superior, overall, from a passenger perspective: the higher hub–hub costs are spread over many passengers and will have only a small effect on fares (everything else being equal), while travel times are much improved.

4.3 Geopolitical method

The wider set of properties taken into consideration for assessing African airports as suitable hubs includes the following elements, described hereafter: passenger demand, airport capacity, and centrality of the hub.

The presence of high originating passenger demand at an airport implies that the airport is already a major player. High demand at hubs has benefits in terms of reducing the need for node–hub links, and reflects some existing infrastructural ability to handle large volumes of passengers. This is also consistent with an apparent airline industry rule of thumb stating that hub cities should contribute at least 30 to 40 per cent of the traffic on each flight.

The presence of adequate airside infrastructure capacity is assessed in terms of the current number of runways and the number of airlines operating at an airport (which reflects the airport's operational capacity in terms of gates, slots, baggage-handling processes, and aircraft turnaround time).

The hub airport should be near the economic heart of the region so that it is able to nurture economic growth through employment, infrastructure growth, and development. Important links have been made in the literature between hub location, good transportation linkages, and local economic development (Button *et al.*, 2006).

Ideally, the hub airport should be located in the centre of the region where the amount of circuitry imposed on node–hub passengers is minimised. The aggregate node–hub distance from all other airports (nodes) in the cluster is used as an indicator.

Following from the findings on the optimal number of hubs derived using the clustering method, a four-cluster network was designed using the geopolitical methodology. As before, cluster boundaries were aligned with the existing Regional Economic Communities (RECs) through which economic cooperation and trust relationships have already been established. In addition, care was taken to ensure that all node–hub distances were below a threshold of 3,500 km, so that low-cost, short-range airplanes could be used if passenger demand was low enough, in line with the earlier findings on the importance of range thresholds in sparse markets.

Table 4 summarises the assessment of the eight candidate hub airports considered.

In the north, three strong candidate airports are Cairo (Egypt), Algiers (Algeria), and Fes Saïss (Morocco). Egypt is, however, eliminated due to the fact that it has very long node–hub distances, even though it has high passenger numbers. Instead, Fes Saïss (Morocco) is chosen because it has the shortest node–hub distances and at present has more airlines serving the airport.

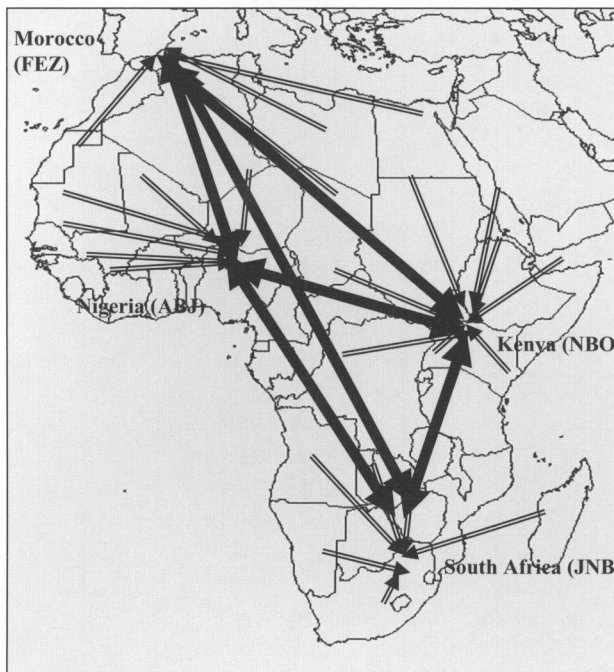
In southern Africa, South Africa currently acts as a hub from Asia to Africa, is a hub to a major airline carrier in the region (South African Airways), and is suitably located within the southern portion of the continent.

In East Africa, the two probable hubs are found in Ethiopia and Kenya. Even though Addis Ababa (Ethiopia) has higher passenger numbers, it has higher total node–hub distances. Nairobi (Kenya), on the other hand, is chosen because it serves more

Table 4
Criteria for Choosing the Most Suitable Hubs in the Geopolitical Method

Item	North			South		East		West	
	FEZ	ALG	CAI	JNB	NBO	ADD	KAN	DKR	
Country	Morocco	Algeria	Egypt	South Africa	Kenya	Ethiopia	Nigeria	Senegal	
Passenger demand numbers	1,329,040	1,329,036	1,242,000	3,669,000	741,000	843,000	252,000	19,500	
Total node-hub distances	13,642	15,069	31,134	11,114	10,360	10,762	33,775	53,093	
Airlines served	16	14	49	42	45	19	36	28	
No. 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, Kenya Airways hub	Ethiopian Airlines hub	Regional hub	Re-fuelling hub	
Hub choice		FEZ		JNB	NBO		KAN		

Figure 4
Geopolitical Network



airlines and has greater runway capacity, as it acts as a major connecting hub for larger carriers such as Kenya Airways and KLM.

In West Africa, Abuja (Nigeria) has higher passenger capacity and shorter node–hub distances within the region, serves more airlines, and is more suitably located in the western portion of the continent than Dakar (Senegal), its competitor.

The resultant four-hub network is shown in Figure 4. The operating cost results in Table 3 show that the geopolitical network also performs best in terms of overall cost, with the exception of the one-hub network. Neither the node–hub costs nor the hub–hub costs are the lowest, but the network seems to achieve a good trade-off between the two by requiring both high passenger demand, and low node–hub and hub–hub distances. However, from the total passenger travel time expenditure it appears that the low operating costs come at the expense of additional travel time, which is 16 per cent higher than that achieved by the modified cluster method for a four-hub network. Which of these solutions is ultimately most suitable will depend on the relative weight placed on operating costs (and thus fares) versus travel time, which is not the subject of this paper.

5.0 Conclusion

The aim of this paper has been to examine the desirability and the implications, from an operating cost and passenger travel time perspective, of moving towards a more

integrated hub-and-spoke network for regional travel by air transport within Africa. The question is of interest because 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 passenger flows typically result in infrequent air services at very high costs. Furthermore, the approach employed combines cost-effectiveness criteria for hub location and using an engineering cost model to calculate network cost in the H&S network.

The most important finding is that an H&S network form seems to hold significant promise for reducing costs and increasing service frequencies to all countries across the continent. The most suitable single-allocation network appears to be one with four clusters. Within these clusters, the most suitable hub airports are those that currently perform a hub function to some extent, albeit at airline level, since they are used by resident flag carriers as a base for local and international connections. These hub airports are Fes Saïss (Morocco), Nairobi (Kenya), Abuja (Nigeria), and Johannesburg (South Africa). These airports have the further advantage of already possessing some (or even considerable) capacity and infrastructure — in contrast to most other airports in Africa — and could be most easily upgraded to network-wide hubs.

Two main reasons why the suggested H&S structure performs well in terms of operating costs are the high numbers of passengers originating at these airports, and the fact that each airport is located more or less centrally within its respective cluster. Both of these factors confirm previous findings regarding optimal hub location in airline networks (Button, 2002; Schnell and Huschelrath, 2004). High originating demand eliminates many node–hub trips and reduces passenger travel time, while central locations reduce node–hub distances in order to take advantage of economies of scale on hub–hub links as quickly as possible.

However, a multi-criteria analysis approach based on a number of quantitative and qualitative criteria performed better in identifying the best-performing hubs than a mechanistic heuristic approach based solely on passenger demand and node–hub distances. The reason for this appears to be related to the non-linearities that exist when the costs of operating airline services in sparse markets are considered. An engineering cost model was used to estimate the least-cost service design for any given route, calibrated with cost and service parameters for the African situation. The model showed that, on thin routes, short-range, low-capacity aircraft may be the least expensive aircraft to use, but that significant jumps occur in the lower cost envelope as soon as the sector distance exceeds the range of these craft. This ‘distance threshold’ effect introduces idiosyncrasies into the network design process, whereby slight adjustments in hub locations within a cluster may lead to large differences in node–hub or hub–hub costs, which may significantly alter the desirability of choosing a particular airport as a hub. The multi-criteria, analysis-based method proved better at capturing these threshold effects as it explicitly aimed to keep all node–hub distances below the lowest threshold of 3,500 km. The distance threshold effect also proved important when considering the likely changes in optimal network form as demand becomes less sparse over time.

Ultimately, this analysis suggests that the choice of airports to act as hubs for intra-continental air transport in Africa is likely to be a process fraught with difficulty. A strong case can be made for moving towards a more integrated continent-wide hub-and-spoke network, as this may deliver significantly improved service to passengers

(particularly with respect to improved frequencies to or from the majority of countries with currently low demand) and may contribute significantly to the financial sustainability of airlines. However, the performance of the network, due to its sparsity, is relatively sensitive to the exact location of the hubs, even among strongly competing hub alternatives with similar levels of infrastructure and demand. The difference in cost between the most suitable and other potential H&S networks is in the order of 17 to 20 per cent, which is fairly significant. A careful process that balances cost with political and technical considerations would have to be followed to move towards a suitable network form in practice.

Further work being pursued as a result of the findings of this study involves determining the optimum network within the African network using simulated annealing methodology, still incorporating the cost model results but without predetermining the hubs. The findings of this work will be compared with the results in this paper.

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