The multi-airline *p*-hub median problem applied to the African aviation market

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Abstract

Despite growth in research on air transport in Africa in recent years, little is known about the adequacy of the infrastructure to sustain potential future air traffic expansion. The continent has experienced growth in domestic, intra- and inter-continental air traffic services over the past two decades that we project will continue over the medium term. Applying a gravity model in which corruption, conflict, common language and land-locked indices contribute to the demand estimation, we forecast annual intra-African growth of 8.1% up to 2030. As witnessed in established markets, deregulation will likely result in hub-spoke network designs in order to accommodate demand efficiently if mobility and access is to be encouraged. In this research, we modify the *p*-hub median problem in order to identify multiple, economically viable, hub-spoke networks that would adequately serve the intra- and inter-continental demand for air transport. Aside from current hubs, namely Cairo (Egypt), Addis Ababa (Ethiopia) and Johannesburg (South Africa), future hubs could include airports in the North that serve European-African flows, such as Algiers, and Nigeria in the West due to its relatively large population and wealth. By 2030, we also find that demand is sufficient to justify an additional hub in central Sub-Saharan Africa, such as Lusaka (Zambia). However, this would be dependent on the implementation of liberalisation policies as set out in the Yamoussoukro Decision.

Keywords: African aviation market, *p*-hub median, demand forecasting, capacity analysis

Highlights

- A multi-airline *p*-hub median model designs multiple airline networks simultaneously
- African inter & intra continental origin-destination aviation markets are analyzed
- Corruption, conflict, land-locked & language indices are significant in gravity model
- By 2030, demand is sufficient to justify Sub-Saharan African hubs such as Lusaka
- Handling 80 million passengers annually by 2030 require African airport investments

1. Introduction

In 2009, Jack Short as the Secretary General of the International Transport Forum argued that transport is a key enabler to achieving economic growth and development as well as integrating the global economy. This has been recognized by the UN, which defined eight of the 17 Sustainable Development Goals to include transport related targets, as signed in September 2015[1]. Since ground-transport infrastructure in Africa is poorly developed and the relative distances are substantial (Teravaninthorn and Raballand, 2009), air transport is the main mode of international flows in Africa and its importance relative to other modes of transport is growing (ATAG, 2003). Moreover, the transport of time-sensitive and perishable exports via aviation links is of substantial interest, given the role of the African agricultural sector that is responsible for 30% of GDP and 70% of employment (NEPAD, 2013) across the continent.

The literature evaluating the economic and social impacts of air transport in Africa continues to grow as more research focuses on the liberalisation of air services on individual countries (Chingosho, 2009; Schlumberger, 2010; InterVISTAS, 2014; Danjuma, et al. 2014; Abate, 2016). However, limited evidence is available on airline

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[1] http://www.un.org/sustainabledevelopment/sustainable-development-goals/ (accessed 12/9/2017).

network structures and hub locations in a deregulated African aviation market, namely a post-Yamoussoukro liberalisation. Ssamula (2012) and Ssamula and Venter (2013) investigate hub and spoke networks in the African context by applying a cluster model in order to search for optimal hubs, after splitting Africa into regions. However international traffic, which represents a large percentage of demand, has generally been ignored. This paper contributes to the literature on hub network design from both methodological and applied research perspectives. We develop a multi-airline *p*-hub model, which we then apply to both current and forecasted future demand in the intra-continental and international African aviation market. The conclusions of such an analysis may provide air transport stakeholders with strategies to design cost-effective hub networks to serve the African market. The model also identifies potentially insufficient infrastructure to meet future demand and should therefore be of use to both policy makers and airport planners.

Planning is critically important given that growth in demand is forecast to outstrip the current development of the African regional air transport infrastructure systems, thus opening gaps between demand and supply that will retard future growth if allowed to persist (Sofreco, 2011). Coupled with the infrastructure challenges, the African air transport industry also faces other challenges in terms of high operating costs and airfares, lack of liberalisation of the intra-African markets, safety and environmental issues (African Development Bank, 2012; African Union, 2017). In line with policies defined in its Agenda 2063, the African Union envisages a long-term transport vision that aims at integrating the continent in an efficient, safe, cost-effective and an environmentally sustainable manner. Organisations such as the International Civil Aviation Organisation and the European Union have demonstrated their commitment to support the African Union and African Regional Economic Communities in achieving efficient and sustainable aviation development in Africa (African Union, 2017).

The contribution of this research to the literature is three fold. First, a new multi-airline *p*-hub median approach is developed which identifies optimal hub and spoke networks serving origin destination demand through cost minimization criteria. Second, a gravity model is developed in order to forecast potential African air travel demand into the medium term considering several macro-economic variables specific to the continent. Third, the multi-airline *p*-hub median model is applied to both current and forecasted data in order to design likely future hub networks, thus providing insights into the critical infrastructure necessary to meet future airport demand in Africa. The underlying assumption of the modelling approaches is based on full implementation of an open skies policy, enabling the construction of efficient airline networks across a deregulated African market in which airlines are free to organize their networks from a purely economic and operational perspective.

The remainder of the paper is organised as follows: Section 2 describes the main features of the multi-airline *p*-hub median model and provides a detailed explanation of each component of the model. Section 3 discusses the characteristics of the African aviation market, the current air transport policy across the continent, the major airlines serving the region and the infrastructure serving these markets. Section 4 documents the process of data collection for the demand estimation utilised by the multi-airline model to assess potentially optimal hub-spoke networks. Section 5 outlines the main features and results of the gravity model and predicted passenger flows for 2030. Section 6 presents the results of the *p*-hub median model, indicating hub positioning in 2014 and 2030 for multiple, potential airline configurations. Finally, Section 7 concludes the paper with recommendations for future research.

2. Multi-airline *p*-hub median model

Research on node optimality may be traced back to Hakimi (1964), who developed the first model to evaluate optimum locations in the cases of communication networks and police stations on a highway system. The first recognised mathematical formulations and solution methods were then proposed in the works of O'Kelly (1986a, 1986b). The models suggested allocating hubs within a network in order to minimise the total transportation cost or time of serving a given set of flows. Since these seminal papers, hub location models have been developed in the literature in several directions. Single and multiple allocation represent the two basic types of hub network formulations. Under single allocation, all traffic is routed via a single hub whereas the multiple allocation models permit spoke traffic to be served by more than one hub. Additional variations consider limited capacity (capacitated) or unrestricted capacity (un-capacitated) at both hub and arc levels. An exhaustive review of the existing methodologies and the solution approaches may be found in Alumur and Kara (2008) and Farahani et al. (2013).

In this work, we develop an un-capacitated, multiple allocation, p-hub median problem defined on a complete network $\mathrm{G} = (N, A)$ with node set $N = \{1,2, \dots, n\}$ and arc set A. Each arc $[i, j]$ is assumed to serve infinite capacity at cost c_{ij}. The node set N is composed of a set of external nodes $\mathrm{EN} = \{1, \dots, f\}$, a set of internal African nodes $\mathrm{IN} = \{f + 1, .., n\}$ and $\omega \epsilon \{EN, IN\}$. The set IN represents the nodes located on the African continent, while EN represents the nodes located outside Africa. In this research, we model the presence of more than one airline operating in the network. The multiple airline p-hub median model selects a complete sub-networks of p hubs, whereby each hub serves flow collection, transfer and distribution. The hub choices are restricted to the subset IN (i.e. the hubs are located within Africa) and the transfer between hubs is discounted by a common discount factor $\alpha \in [0,1]$.

The α discount factor is introduced in order to account for economies of scale and density, which is the underlying reason for the creation of hub-spoke systems (Adler, 2001). As specified in Ernst et al. (2009), the discount on hub arcs accounts for the larger planes and higher staff utilization employed on links between major hubs that would not be economical to use over the other edges. It should also be noted that Bryan (1998) and O'Kelly and Bryan (1998) argue that traffic between some inter-hub links may be too low to exploit economies of scale. To address this issue, different approaches have been developed as discussed in an extensive review by Luer-Villagra and Marianov (2013). Consequently, as with most applications to date, we set the discount factor exogenously and subsequently undertake a series of sensitivity analyses. One alternative would be to endogenise the discount factor, for example through a piece-wise linear function, however this would substantially increase the number of variables and constraints, raising difficulties in solving the optimisation problem or requiring a reduction in the number of nodes to be analysed. Our preference to analyse the entire African continent covering 59 states, plus nine external nodes, led us to prefer the sensitivity analysis approach.

Certain nodes may be pre-defined as hubs, for example in the city in which the airline is headquartered. We assume that hubs cannot be shared between different airlines although this restriction could be removed if deemed unnecessary. The only airport across the globe serving more than one hub carrier is Chicago O'Hare, therefore we assume that each African airline will dominate specific airports by controlling a substantial number of slots thus preventing other airlines from entry. In order to characterize the flows between EN and IN sets, we define direct air traffic service (D_{ij}) thus any arc connecting the sets may be served without being part of a hub and spoke network. In this way, we consider foreign carrier service in addition to the African hub-spoke network airlines. The direct connections offered may however be restricted as a function of the bi-lateral agreements between countries, if deemed necessary.

The input data includes the node sets EN and IN, the number of airlines (a), the number of hubs permitted (p) per airline a, the origin-destination demand (W_{ij}), the discount factor α and the minimum demand level to serve direct flights (τ). The cost per unit of flow between two nodes (i, j) routed via hubs k and m is given by $C_{ijkm} = c_{ik} + \alpha c_{km} + c_{mj}$, where the costs are a function of the distance between the nodes (with $c_{ii} = 0$). The cost parameters C_{ijkm} are computed by multiplying the cost per available seat kilometre (CASK) published in the Standard Inputs for Eurocontrol Cost Benefit Analyses (2013 edition) with the great circle distance between the relevant nodes. The direct operating costs are linked to aircraft operations and include crew, fuel, landing fees, ground handling, aircraft parking, air bridges and maintenance. For each of the three aircraft categories published, namely wide-body, narrow-body and regional jets, we compute the average CASK. We assume that wide-body aircraft serve long distance markets (distance > 5,000 km), narrow-bodies serve distances between 1,000 and 5,000 km and regional jets are utilized in the short distance markets (distance < 1,000 km), as suggested in Swan and Adler (2006). Table 3 presents the CASK values used in this research. We thus assume symmetry in direct operating costs across airlines. Future research could utilize specific African airline costs for greater accuracy in the analysis of specific markets were such data to be made publicly available.

Table 3: Costs per Available Seat Kilometre

	Short Haul	**Medium Haul**	**Long Haul**
Euro per ASK	0.0471	0.0366	0.0372

Based on the linearization presented in Skorin-Kapov et al. (1996), we formulate the multi-airline *p*-hub median problem as described in Equations (1-6).

$$\min_{X^a_{ijkm}, D_{ij}, y^a_k} \sum_a \sum_i \sum_j \sum_k \sum_m W_{ij}\, C_{ijkm}\, X^a_{ijkm} + \sum_{i\in\omega} \sum_{j\in N\backslash\omega} W_{ij}\, c_{ij}\, D_{ij} \tag{1}$$

subject to

$$\sum_{m=1}^{n} X^a_{ijkm} \le y^a_k \quad \forall\, i,j,k,a \tag{2a}$$

$$\sum_{k=1}^{n} X^a_{ijkm} \le y^a_m \quad \forall\, i,j,m,a \tag{2b}$$

$$\sum_{a}^{A} \sum_{k=1}^{n} \sum_{m=1}^{n} X^a_{ijkm} + D_{ij} = 1 \quad \forall\, i \in \omega, j \in N\backslash\omega \tag{3}$$

$$\sum_{k=1}^{n} y^a_k = p \quad \forall\, a \tag{4a}$$

$$\sum_{k=1}^{f} y^a_k = 0 \quad \forall\, a \tag{4b}$$

$$\sum_{a}^{A} y^a_k \le 1 \;\; \forall\, k \tag{4c}$$

$$W_{ij} D_{ij} \ge \tau B_{ij} \; \forall\, i \in \omega\,, j \in N\backslash\omega \tag{5a}$$

$$W_{ij} D_{ij} \le M B_{ij} \; \forall\, i \in \omega\,, j \in N\backslash\omega \tag{5b}$$

$$0 \le X^a_{ijkm} \le 1, 0 \le D_{ij} \le \gamma, y^a_k \textit{ and } B_{ij} \textit{ binary} \tag{6}$$

The objective function (1) minimizes the costs associated with serving passenger demand using a hub and spoke system (X^a_{ijkm}) and direct flights (D_{ij}). The first element of the objective function sums the cost of a airlines, indicating that the sub-networks are chosen in order to minimize the complete African system costs, in line with a pan-African perspective. Constraints (2) specify that passenger flows are routed via one (2a) or two hubs (2b). Constraint (3) ensures that the arcs (i, j) are served by a sub-network X^a_{ijkm} or by a direct flight D_{ij}. Constraint (4a) specifies the total number of hubs per airline, Constraint (4b) ensures that only nodes from the IN set may be chosen as hub locations and Constraint (4c) specifies that hubs cannot be shared between different airlines. Constraint (5a) permits direct connections if and only if the demand between the nodes is greater than parameter τ and Constraint (5b) ensures feasibility, with large number M set greater than the maximum flow and B_{ij} a set of auxiliary binary variables. In order to simulate bilateral agreements on the flows between internal and external nodes, we also limit the maximum flow served by direct flights to a γ percentage of demand (i.e. $0 \leq D_{ij} \leq \gamma$) where relevant as stated in the upper and lower bounds of Equations (6). This constraint ensures reciprocity between countries such that supply is served by the African and non-African airlines on an equal basis. The latter airline carriers are thus modelled indirectly.

Another assumption of the model is that traffic between nodes is allocated to the airline with the lowest variable cost. The argument is two-fold; (1) producers with lower marginal costs will be in a position to set their prices lower than their competitors thus attracting the largest market share; and (2) origin-destination demand may be served over the same path because there are no restrictions on the node or arc capacities. A possible alternative would be to set a maximum airline capacity per arc thus considering airline fleet size. On the other hand, such constraints would introduce additional assumptions with regard to fleet composition, availability and allocation. Another alternative would be to model competition between the airlines directly. Competition may be implemented through a sequential location approach in which an incumbent serves the network and an entrant airline enters the market (Eiselt and Marianov, 2009 and Luer-Villagra and Marianov, 2013). However, in this case market share is allocated on the basis of cost minimisation, similar to the standard approach. Finally, a Nash equilibrium game could analyse market share using a nested logit function in order to distribute demand (Adler, 2005 and Adler and Smilowitz, 2007). However, this approach requires extensive knowledge of the airline profit functions, which is currently difficult to ascertain in detail in the African markets from publicly available data.

3. African Aviation

Despite its great potential, Africa remains the weakest region worldwide, representing around 2.2% of global passengers carried and 3% of aircraft departures according to ICAO[2]. At least 2,900 airports are dispersed across the African continent of which a

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[2] http://www.icao.int/sustainability/Pages/FactsFigures.aspx

tenth receive scheduled services. Africa's busiest airports include Johannesburg, Cairo and Addis Ababa airports, which act as gateways to Africa for inter-continental traffic. In 2014, African airports carried 180 million passengers, of which 64% were inter-continental. In terms of freight, 51.3 million metric tons of cargo was transported worldwide by air, of which 1.9 metric million tons were handled at African airports (ACI 2015). According to AFRAA (2015), there were 2.9 million aircraft movements in 2014, with the top five African airports accounting for 23% of all movements (Figure 1).

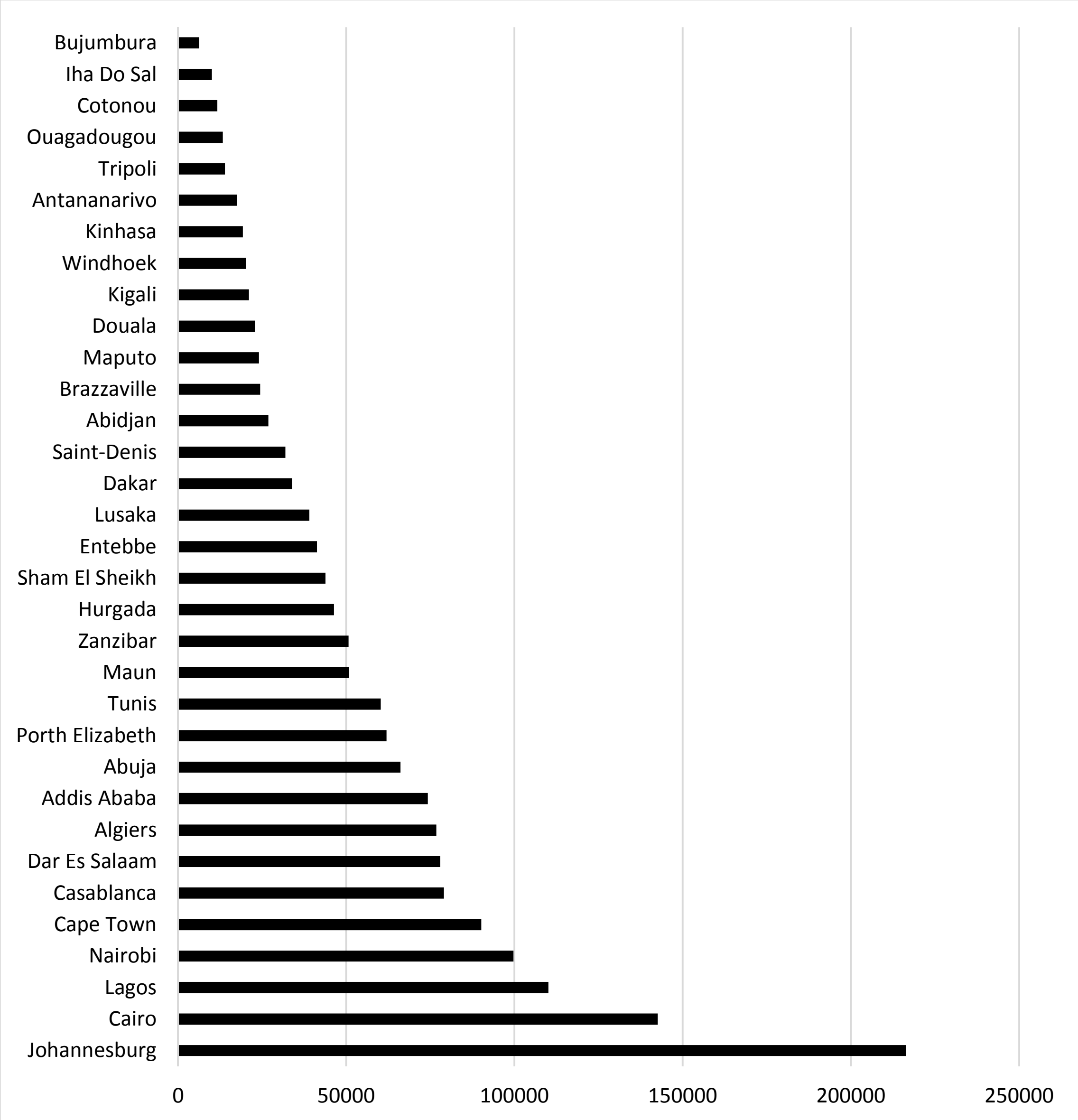

Figure 1: Twenty busiest African airports in 2014 by annual aircraft movements

The propensity to fly in Africa varies from 0.01 to 0.9 air trips per capita in the Democratic Republic of Congo and South Africa with a GDP per capita of $442 and $6,480, respectively. With a few exceptions, such as routes connecting large cities, the intra-African routes can generally be classified as thin and fragmented markets. The largest intra-African market is Harare – Johannesburg (estimated to be around 500 passengers per day in both directions), with the next largest being Cairo to Khartoum (SH&E, 2010). The largest operators of intra-African routes in terms of capacity cover the East, North and South of Africa, which demonstrates an imbalance in the regional distribution of traffic. Indeed, the continent has weak internal links compared to the stronger external flows, with the latter being predominantly served by non-African airlines (AFRAA, 2014). However, the pan-African route network represents an important core market for African airlines due to the intense competition on external links. Hence, there is general consensus that the slow pace of liberalisation remains a major barrier to intra-African air connectivity. Intra-African hub-and-spoke networks are centred on five cities, namely Addis Ababa, Cairo, Casablanca, Johannesburg and Nairobi, accounting for around 80% of all scheduled capacity within Africa (FlightStats, May 2013).

Table 1: Twenty largest African airports by passengers carried in 2014

City/country	Passengers	No. of Runways	No. of Terminals
Johannesburg[3] / South Africa	19,028,969	2	7
Cairo / Egypt	13,842,615	3	3 (2 in construction)
Cape Town / South Africa	8,636,294	2	5
Casablanca / Morocco	7,946,504	2	2
Lagos / Nigeria	7,309,081	2	2
Hurghada / Egypt	7,223,136	2	2
Addis Ababa / Ethiopia	6,931,044	2	2
Algiers / Algeria	6,457,795	2	2
Nairobi / Kenya	5,305,078	1	1 (1 in construction)

[3] Johannesburg, Cape Town and Durban airports are the only co-ordinated airports in South Africa (Comair, 2006).

Sharm El Sheikh / Egypt	6,235,864	2	2
Tunis / Tunisia	5,117,920	2	2
Abuja / Nigeria	4,569,792	2	2
Durban / South Africa	4,495,974	1	1
Marrakech / Morocco	4,001,463	1	1
Khartoum / Sudan	2,795,913	1	1
Plaine Magnien / Mauritius	2,762,935	1	1
Accra / Ghana	2,369,538	1	1
Borg El Arab / Egypt	2,501,704	3	3
Dar es Salam / Tanzania	2,347,341	2	2
Enfidha / Tunisia	2,174,538	1	1

Source: CAPA Profiles Airports and AFRAA, 2015

In the rest of this section, we first discuss the liberalisation policies to date, then the airlines serving the pan-African market and finally, the infrastructure necessary to support the system.

3.1 African Aviation Policy

The Yamoussoukro Decision (YD) was signed in 1999 and created a comprehensive policy framework with the stated aim of liberalising air transport across Africa. YD was intended to liberalize the intra-African air transport services by eliminating restrictions on frequency, capacity and tariffs as well as freely granting commercial traffic rights with respect to third, fourth and fifth air freedoms. Recent studies have shown that the implementation of the YD is still notoriously slow owing to a number of factors including the huge disparity in economic development and great variance in carrier size and competitiveness across the African airline industry (Schlumberger, 2010; Pirie, 2014; Njoya, 2016).

Schlumberger (2010) argues that while progress has been achieved towards more market-oriented aviation policies at regional levels, the pan-African level implementation has been slow and incomplete. Unlike North and Southern Africa that have not implemented the YD, West and Central Africa have fully implemented the liberalization of air services. Njoya (2016) reviews the slow implementation of YD and argues that private sector-led cooperative arrangements between states and regional airline groupings have helped to counteract market access restrictions. Pirie (2014) highlights the political climate and complexity of the geography of air transport across the continent at inter-continental, continental and domestic scales. The complexity is partly explained by the multitude of local, sub-regional, regional and international governmental organisations involved in both the political and economic provision of airline and airport infrastructure access rights.

The relationship between air transport policy and the performance of the African aviation sector has been the subject of several papers over the last decade (Myburgh et al., 2006; Chingosho, 2009; Schlumberger, 2010; InterVISTAS, 2014). Chingosho (2009) provides a comprehensive overview of the African airline industry, including the liberalization process, highlighting that Africa has been left out of the worldwide trend of major alliances and consolidation. Analysing air transport routes to and from Addis Ababa using a gravity model, Abate (2016) argues that although liberalisation has not impacted prices, it has brought about a 40% increase in the level of air traffic movements. Fares did not decline because liberalisation did not result in new entrants therefore incumbent airlines felt no pressure to reduce fares. Similarly, Surovitskikh and Lubbe (2015) find a significant relationship between South Africa's aviation policy and air passenger traffic flows in three markets, namely South Africa to intra-Africa (36-45% traffic increase depending on the air service liberalization index used), South-Africa to Southern Africa (21-25%) and South-Africa to East Africa (9-20%) from 2000 to 2006. Danjuma et al. (2014) argue that liberalization of bilateral air services in Nigeria would stimulate traffic by at least 65 %. Daramola and Jaja (2011) argue that some of the effects of deregulation of domestic air services in Nigeria have been consistent with observed trends in other countries, such as the abandonment of less profitable routes in the short term. However, unlike the US domestic deregulation that resulted in the rising concentration of connectivity across a limited numbers of nodes, deregulation in Nigeria appears to be linked to a dispersal of interactions across the network. Moreover, whilst Lagos and Abuja are major hubs acting as pivotal nodes for many airlines, the network is still served as a point-to-point model. This is attributable to the differences in industry structure and service at the time deregulation was introduced. In conclusion, the limited and fragmented bilateral and multilateral liberalisation in Africa as well as the slow implementation of the YD has made it difficult for African airlines to grow and compete effectively at the pan-African level.

3.2 African Airlines

Intra-African air transport is dominated by five carriers, namely Egypt Air, South African Airways, Ethiopian Airlines, Royal Air Maroc and Kenya Airways. These are the only African airlines that transport over five million passengers annually and together they account for around 80% of all scheduled movement within Africa. The 100% state owned Ethiopian Airlines is the fastest growing and the most profitable airline on the continent. Founded in April 1946, the airline operates scheduled services to 92 international destinations (of which 51 are located in Africa) and 19 domestic destinations in 2015. It also operates the largest aircraft fleet in Africa, namely 79 in operation and 42 on order. Table 2 presents data on the 10 largest African Airline groups ranked by number of aircraft and African destinations.

Table 2: Top ten African airlines by aircraft fleet

Airline	Wide-body	Narrow-body	Regional	Total	International destinations (within Africa)
Ethiopian Airlines	33	26	20	79	92 (51)
Egypt Air	20	36	12	68	69 (23)
South African Airways	23	41	0	64	56 (26)
Royal Air Maroc	6	37	9	52	94 (31)
Air Algerie	8	22	16	46	71 (12)
Kenya Airways	13	12	17	42	62 (30)
Lybian Airlines	3	7	19	39	22 (14)
Tunisair	2	28	0	30	53 (10)
Comair (South African)	0	27	0	27	(6)
Arik Air	4	13	9	26	14 (11)

Source: CAPA, 13 January 2015 and airline's website

Ethiopian Airlines is an exception in Africa in terms of airline performance. AFRAA (2014) points out that many African airlines are characterised by inefficiencies and poor load factors (69.6% in 2013 compared to the global average load factor of 79.9%) which are attributed to the imbalance of capacity and demand, limited commercial co-operation and un-coordinated intra-African networks. While many African airlines remain state owned, airline growth in the region is now drawing from the increase in low cost carrier (LCC) presence. Thus, the African industry has seen a new breed of private carriers operating largely in the domestic and regional markets (Amankwah-Amoah and Debrah, 2009; Schlumberger and Weisskopf, 2014). Schlumberger and Weisskopf (2014) study the potential of LCCs in developing countries with a focus on factors conducive to such growth. Clearly, the African market environment has prevented African airlines from achieving cost economies that can result from larger-scale operations and greater network spread. Moreover, the environment is characterised by relatively weak demand, extensive government regulation, inadequate infrastructure, safety and security challenges, low internet penetration, skill shortages and high fuel prices, fees and taxes. For example, African airlines heavily rely on traditional channels to distribute their service and therefore cannot exploit the benefits of online sales owing to low Internet penetration (estimated by Internet World Stats at 28.6% in 2015) and low debit or credit card penetration (estimated at below 5% in 2015).

Heinz and O'Connell (2013) investigate the applicability of airline business models traditionally defined within the European and North American contexts to the African market. Given the heterogeneity of African markets, the LCC model is likely to be suitable in Northern and Southern Africa because demand is sufficiently strong, whereas in West Africa, the authors argue that the regional carrier model is more likely to dominate. However, the long distances and thin demand of the inter-regional markets are best suited to full-service network carriers, which aggregate sparse demand through a hub, thereby overcoming low load factors. The authors conclude that full-service network carriers and regional airlines are the most prominent and stable in the African market in terms of consistent profitability due to network density and connectivity. Consequently, without adequate aviation infrastructure, African aviation may not be in a position to capitalise on growth.

3.3 African Infrastructure

Airport infrastructure, air traffic management organization and a culture of safety are often listed as the key enablers of air traffic flows and as the major challenges to growth in Africa. In a recent study jointly commissioned by NEPAD, the African Union and AfDB, regional infrastructure gaps in Africa were identified which included the need to expand seven airports due to expected additional demand of over 2 million passengers per year by 2030 and 3 million passengers per year by 2040 (Sofreco, 2011). The study further found that demand for 17 additional airports will exceed capacity by 2020 under base case forecasts and that all regions of the continent will require expansion of existing airports or new airports by 2040 in order to handle the anticipated growth of air traffic.

Despite increasing private sector participation in the African aviation sector, most of the air transport infrastructure is stated owned, inadequate, and lacks sufficient funding (Proparco, 2016). A few studies have focused on the question of hub location in Africa. Ssamula (2012) argues that hubbing is advantageous for shorter intra-African routes with low passenger demand, whereas some of the high passenger demand routes may be operated profitably either as direct routes or as routes within a hub-spoke network. After splitting Africa into regions, Ssamula and Venter (2013) apply a clustering method and network cost model to examine suitable hub locations in Africa. The authors argue that regional jets have a significant role to play in low-density hub-and-spoke operations, which led them to conclude that a four-hub network centred on high-demand hubs with short node-hub distances is the most suitable option in Africa. The main advantages of hubbing as identified in the literature include lower costs of travel (O'Kelly et al., 1996), economies of scale and improved capacity allocation (Barla and Constantos, 2000), increased accessibility (Button et al., 2002), higher flight frequencies (Schnell and Huschelrath, 2004) and aggregation of demand (Adler, 2005). Some disadvantages include increased travel times (Button et al., 2002) and additional operating costs (Zollinger, 1995).

4. African Case Study

An MIDT-database provided the origin destination (OD) demand data for the years 2010 to 2014 (Travelport Global Distribution System (GDS)). Given the low penetration and usage of internet services, bookings from Africa rely heavily on airline ticket distribution offices and travel agencies that utilize GDSs. Bookings made directly through airlines are not collected through the GDS, however Travelport corrects the information in order to estimate the size of the relevant markets. Using the corrected OD demand instead of seats offered, we are able to design a network that is less influenced by the existing network structure. In order to restrict the number of nodes for computational reasons, we aggregate the OD demand thus ensuring reasonable run times for the large-scale, mixed integer linear program. Table 4 presents the nine external nodes chosen, each representing the highest demand per geographic region.

Table 4: External node set

Geographic Region	External Node
Western Europe	Paris
Eastern & Central Europe	Moscow
Middle East	Jeddah
North America	New York
Latin America, Central America & Caribbean	Sao Paulo
South West Pacific	Perth
North East Asia	Beijing
South East Asia	Kuala Lumpur
Central & South Asia	Mumbai

With respect to the African nodes (IN), we aggregate demand per country, choosing the representative node with the highest OD demand thus ensuring that all countries are represented. The only exceptions are Egypt, Morocco, Nigeria and South Africa, where more than one node is considered given the relatively higher levels of demand. In these four cases, the OD demand is aggregated according to the geographically closest open node. Table 5 presents the list of 59 African nodes analysed.

Table 5: African airport dataset

Country	Node	Country	Node	Country	Node
Algeria	Algiers	**Ethiopia**	Addis Ababa	**Nigeria**	Abuja
Angola	Luanda	**Gabon**	Libreville		Lagos
Benin	Cotonou	**Gambia**	Banjul	**Rwanda**	Kigali
Botswana	Gaborone	**Ghana**	Accra	**Sao Tome & Principe**	Sao Tome
Burkina Faso	Ouagadougou	**Guinea**	Conakry	**Senegal**	Dakar
Burundi	Bujumbura	**Guinea-Bissau**	Bissau	**Seychelles**	Mahe Island
Cameroon	Douala	**Kenya**	Nairobi	**Sierra Leone**	Freetown
Cape Verde	Praia	**Lesotho**	Maseru	**Somalia**	Mogadishu
Central African Republic	Bangui	**Liberia**	Monrovia	**South Africa**	Cape Town
Chad	N'djamena	**Libya**	Tripoli		Durban
Comoros	Moroni	**Madagascar**	Antananarivo		Johannesburg
Congo	Brazzaville	**Malawi**	Lilongwe	**South Sudan**	Juba
DR Congo	Kinshasa	**Mali**	Bamako	**Sudan**	Khartoum
Cote D'Ivoire	Abidjan	**Mauritania**	Nouakchott	**Tanzania**	Dar Es Salaam
Djibouti	Djibouti	**Mauritius**	Mauritius	**Togo**	Lome

Egypt	Alexandria	**Morocco**	Casablanca	**Tunisia**	Tunis
	Cairo		Marrakech	**Uganda**	Entebbe
	Hurghada	**Mozambique**	Maputo	**Zambia**	Lusaka
Equatorial Guinea	Malabo	**Namibia**	Windhoek	**Zimbabwe**	Harare
Eritrea	Asmara	**Niger**	Niamey		

In summation, we consider 68 nodes and a total OD demand of 127 million passengers for 2014. Figure 2 shows the position of each of the African nodes included in the analysis, the traffic magnitude represented by the size of the pie and the distribution of traffic between intra-continental (black or dark slices) and inter-continental (red or light slices). The largest portion of traffic is concentrated in the North African region with most of the sub Saharan countries (with the exception of South Africa) showing a markedly lower level of passenger demand. Differences can also be observed in the air demand composition, with the share of intra-African demand increasing while moving from the North to the South of the continent.

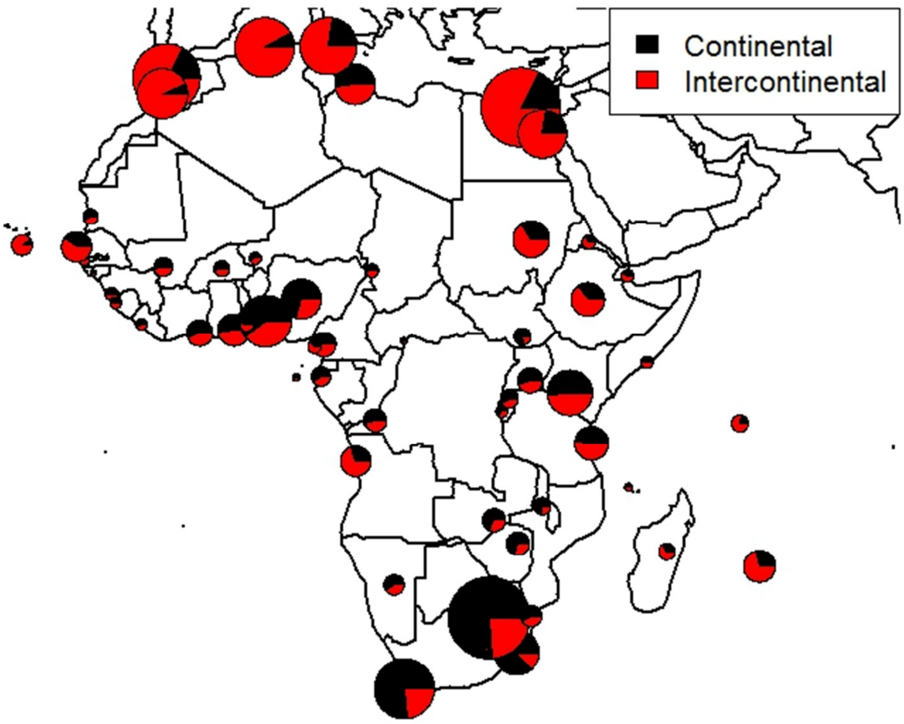

Figure 2: African airports and their traffic share in 2014

Table 6 presents the share of demand with respect to the origin. The largest share of demand draws from Western Europe (49%) and the Middle East (19%), the two continents closest to North Africa, while the intra-African demand represents 28% of the total demand, approximately 35 million passengers annually.

Table 6: Passenger distribution according to origin in 2014

Region	Market Share
Western Europe	39%
Intra-Africa	**28%**
Middle East	19%
North America	4%
North East Asia	3%
Eastern and Central Europe	2%
Central and South Asia	2%
South East Asia	1%
Latin America, Central America and Caribbean	1%
South West Pacific	1%

Table 7 lists the top ten OD return routes in terms of passengers in 2014 based on our database. Unlike other continents, the highest demand is for inter-continental routes, representing seven of the ten routes. The only internal OD routes greater than one million return passengers are domestic, namely Nigerian routes between Abuja and Lagos, and South African routes, in the triangle serving Durban, Cape Town and Johannesburg.

Table 7: Top ten aggregated return passenger demand in 2014

Origin Destination	Passengers
Middle East – Cairo	9,449,552
West Europe – Casablanca	7,862,554
West Europe – Algiers	6,791,329
West Europe – Marrakesh	5,982,733
West Europe – Tunis	5,204,840
Cape Town - Johannesburg	5,001,344
Durban – Johannesburg	3,097,052
Abuja – Lagos	2,402,162
Middle East – Alexandria	2,387,805
West Europe– Cairo	2,361,882

5. Air Demand Forecast

In order to design the 2030 hub-spoke networks, we forecast the demand for air travel between each of the nodes in the dataset. Traffic between internal and external nodes is forecasted by applying the expected growth rate for air transport demand between continents provided in the Boeing current market outlook 2015-2034. Traffic between African nodes is forecasted using a gravity model. Gravity models have been applied extensively to model policy effects in bilateral air traffic flows (Dresner and Tretheway, 1992; Schipper et al, 2002; Adler and Hashai, 2005; InterVISTAS-ga2, 2006; Boileau and Vesselolovsky, 2013; InterVISTAS, 2014; Cristea et al., 2015). The gravity model used in transportation research attempts to estimate the volume of traffic between two countries in proportion to the generation and attraction forces (such as income and population) and inversely proportional to impedance factors (examples include cost of travel, regulatory issues and political instability). Considering all the (i, j) combinations of the internal nodes (with $i \neq j$) and the time variable $t = 2010, \dots ,2014$, the model estimated is presented in Equation (7).

$$\begin{aligned} ln(D_{ijt} + 1) = {} & \beta_1 ln(GDP_{it} * GDP_{jt}) + \beta_2 ln(Pop_{it} * Pop_{jt}) \\ & + \beta_3 ln(|GDP_{it} - GDP_{jt}|) + \beta_4 ln(Distance_{ij}) \\ & + \beta_5 ln(CPI_{it} + CPI_{jt}) + \beta_6 ln(Conflict_{it} + Conflict_{jt}) \\ & + \beta_7 (D_i^{Land} + D_j^{Land}) + \beta_8 D_{ij}^{Lang} + \beta_9 D_{ijt}^{zero} + \beta_{10} D_{ijt}^{H} + \varepsilon_{ijt} \end{aligned} \quad (7)$$

where D_{ijt} is the OD return demand in period t, GDP the gross domestic product, Pop the population, $|GDP_{it} - GDP_{jt}|$ the absolute size of the gap in wealth between the two countries, $Distance$ the great-circle distance between the nodes, CPI the corruption index and *Conflict* an index defining the risk of violence in a country.[4] We note that the corruption index value runs from 0 to 10 with the higher value representing lower levels of corruption. The conflict index runs from 0 to 10 with lower values representing a lower likelihood of conflict. A series of dummies are introduced to control for landlocked countries (D^{Land}), common first language (D^{Lang}), OD routes with no demand (D^{zero}) and routes with demand greater than 100 thousand (D^{H}). In line with the previous literature, we assume that the higher the GDP

[4] Transparency International: http://www.transparency.org/research/cpi/overview publishes the Global Conflict Risk Index (GCRI): http://conflictrisk.jrc.ec.europa.eu/

and population and the lower the distance and gap in wealth, the higher the passenger flows between countries (Dresner and Tretheway, 1992; Schipper et al, 2002). With respect to the additional variables, we assume that the lower the level of corruption and likelihood of conflict, the higher is the likely demand. Speaking a common language is also likely to contribute to trade between countries. Finally, it would appear that landlocked countries tend to suffer from weaker economies, which has a stronger negative impact on demand flows than the lack of ports, which should theoretically strengthen the importance of aviation in such countries (Borchert et al., 2012; Button et al., 2015). Descriptive statistics for the variables are presented in Table 8.

Table 8: Descriptive macro-economic statistics

	2014			2030		
Variable	**Average**	**Min**	**Max**	**Average**	**Min**	**Max**
GDP (billion $)	41	0.2	469	86	0.5	1,047
Population (million)	21	0.09	178	30	0.09	273
Corruption Index	3.2	0.8	6.3	4	1	7.8
Conflict Index	4	0	10	4	0	10

Nigeria is the country with both the highest level of GDP ($469 billion) and population (178 million). Sao Tome and Principe exhibit the lowest levels of GDP ($0.24 billion) whilst the Seychelles has the smallest population (91 thousand). With respect to the corruption index, Botswana receives the highest score hence is the least corrupt (6.3) whilst Somalia and Sierra Leone receive the lowest score (0.8). Furthermore, the African population is estimated to increase from 1.14 billion to 1.63 by 2030, whilst GDP is expected to double from $2,202 to $4,635 billion in standardized 2010 US dollars (source: the World Bank database).

We estimate Equation (7) by applying a panel data, random effects, maximum likelihood model and Table 9 presents the variable coefficients, standard errors and significance levels.

Table 9: Gravity model passenger demand parameter estimates

	Estimate	Std. Error	Significance
$ln(GDP_{i,t} * GDP_{j,t})$	0.225	0.012	***
$ln(Pop_{i,t} * Pop_{j,t})$	0.231	0.007	***
$ln(\lvert GDP_{i,t} - GDP_{j,t}\rvert)$	- 0.131	0.015	***
$ln(Distance_{ij})$	- 0.071	0.025	***
$ln(CPI_{i,t} + CPI_{j,t})$	0.131	0.013	***
$ln(Conflict_{i,t} + Conflict_{j,t})$	- 0.034	0.005	***
$D_i^{Land} + D_j^{Land}$	- 0.141	0.034	***
D_{ij}^{Lang}	0.555	0.040	***
$D_{ij,t}^{zero}$	- 7.811	0.053	***
$D_{ij,t}^{H}$	2.426	0.128	***

Adj. R-Squared	0.78
Number of obs.	8,555

*, ** and *** show the level of significance at 10%, 5% and 1%, respectively.

All the explanatory variables are statistically significant and show the expected signs. The results are in line with the literature (Adler and Hashai, 2005), with flows increasing in GDP, population, lower corruption levels and common language. Equally, demand flows decrease the less similar the countries with respect to wealth, the longer the distance, the greater the level of conflict and the landlocked status.

The estimated parameters of Equation (7) are then applied in order to forecast the 2030 OD demand. The estimated levels of GDP and population for 2030 are gathered from the World Bank database. The 2030 corruption index is estimated using an annual trend of 0.17% based on historical data which indicates that the level of corruption is decreasing gradually over time (since 10 indicates no corruption and 0 indicates extreme levels). The conflict index is assumed to remain at the same level as 2014 due to a lack of knowledge with respect to potential changes. Based on the coefficients of Table 9, we then calculate the intra-African OD demand for 2030. We forecast a 2030 total demand (internal and external) of 350 million up from the 127 million in 2014, which represents an annual average increase of 8.16%. Figures 3a and 3b highlight the OD routes over one million passengers for 2014 and 2030, respectively. Inter-continental routes are in red (light) while the intra-continental routes are black (dark) and thicker lines highlight routes serving more than five million passengers. In general, we forecast an increasing importance of intra-African markets particularly in the central and southern regions of the continent, as well as an increase in the inter-continental flights serving North America and Asia.

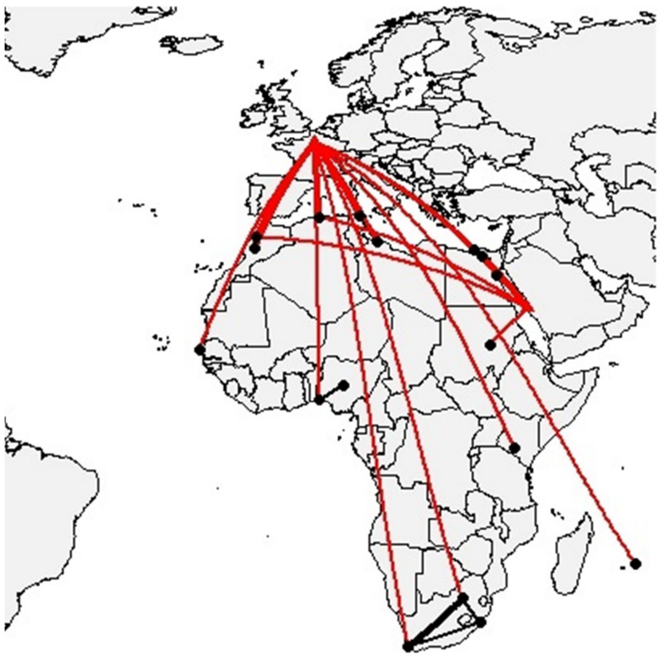

Figure 3a: Current passenger flows over one million in 2014

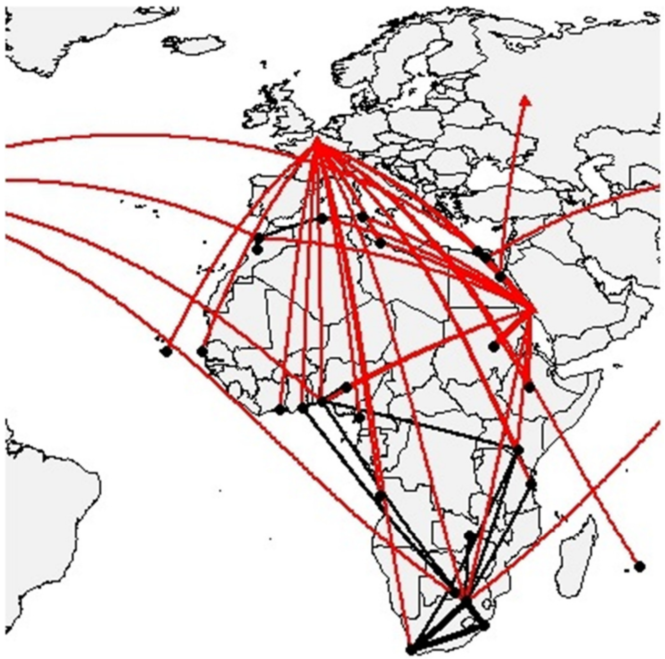

Figure 3b: Forecasted passenger flows greater than one million in 2030

6. Result of the multi-airline p-hub median model

First, we discuss the solution to the p-hub median model developed in section 2 and applied to the 2014 African data. Similar to the current situation in mature markets such as Europe and the United States, we assume that the African network will be served by at least three major network carriers ($\alpha = 3$). We therefore consider the current three largest airlines (EgyptAir, Ethiopian Airlines and South African Airlines) and their respective headquarters located in Egypt (Cairo), Ethiopia (Addis Ababa) and South Africa (Johannesburg) as the location for three hubs. Moreover, we assume that each airline will establish a total of two hubs (i.e. $p = 2$) in the African continent. We apply the model over a range of potential intra-hub discount factors (i.e. $\alpha = 0.7, 0.8$ and 0.9). The lower levels, indicating strong economies of scale, suggest three airlines will serve the continent through dual hubs whereas the higher discount factors suggest that up to six airlines serve the markets with connections via alliances or codeshare agreements. Finally, the model includes direct flights between internal and external nodes provided return demand meets a threshold of at least 100,000 passengers (i.e. $\tau = 25{,}000$). Moreover, we assume that foreign carriers may serve a maximum 50% market share due to bilateral agreements (i.e. $\gamma = 0.5$).

Table 10 summarizes the hub choices as a function of the three discount factors. The results appear to be reasonably robust to changes in the discount factor except for the shift from Tunisia (Tunis) to Kenya (Nairobi) when the cost savings on flows between hubs is relatively low (i.e. $\alpha = 0.9$). Not surprisingly, the model suggests the positioning of several hubs in the North of Africa (Egypt, Tunisia and Algeria) in order to accommodate the relatively substantial demand between Europe and North Africa.

Table 10: Hub selection in 2014

Hub at Headquarters	**Second Hub**		
	$\alpha = 0.7$	$\alpha = 0.8$	$\alpha = 0.9$
Ethiopia (Addis Ababa)	Tunisia (Tunis)	Tunisia (Tunis)	Nigeria (Abuja)
Egypt (Cairo)	Nigeria (Abuja)	Nigeria (Abuja)	Kenya (Nairobi)

South Africa (Johannesburg)	Algeria (Algiers)	Algeria (Algiers)	Algeria (Algiers)

When applying the model to 2030 data forecasts, Algiers and Abuja (or Lagos) remain as preferable hub choices. The main difference is the creation of a hub in Zambia (Lusaka) in preference to Tunisia (Tunis). This result is in line with the expected increase in demand for central and southern Africa, suggesting that a more central location would be advantageous given sufficient demand in Sub-Saharan Africa. As shown in table 11, the only variation due to the change in the discount factor is the shift from Abuja to Lagos, both Nigerian cities, suggesting that the results are reasonably robust to the cost parameters.

Table 11: Hub selection in 2030

Hub at Headquarters	**Second Hub**		
	$\alpha = 0.7$	$\alpha = 0.8$	$\alpha = 0.9$
Ethiopia (Addis Ababa)	Algeria (Algiers)	Algeria (Algiers)	Zambia (Lusaka)
Egypt (Cairo)	Zambia (Lusaka)	Zambia (Lusaka)	Algeria (Algiers)
South Africa (Johannesburg)	Nigeria (Lagos)	Nigeria (Lagos)	Nigeria (Abuja)

Given the hub carrier choices and any direct link served by foreign carriers, Table 12 reports passenger throughput were the African airlines free to develop hub-spoke systems across the continent. For purposes of comparison, the second column lists passenger throughput in 2014 based on data from an ACI report (2015).

Table 12: Passenger flows via potential hubs in 2014 (in parenthesis the % of transfer passengers)

Country	**Passengers**			
	2014 DATA	**0.7**	**0.8**	**0.9**
Nigeria (Abuja)	7,728,456	13,669,693 (70%)	13,600,815 (70%)	14,270,309 (70%)

Ethiopia (Addis Ababa)	7,083,173	18,278,862 (83%)	17,692,100 (83%)	8,568,992 (65%)
Algeria (Algiers)	8,474,885	28,337,311 (67%)	27,686,829 (66%)	32,255,190 (71%)
Egypt (Cairo)	15,935,156	22,784,765 (28%)	21,566,939 (24%)	25,099,835 (35%)
South Africa (Johannesburg)	19,948,874	24,272,922 (28%)	23,730,200 (27%)	21,662,396 (20%)
Kenya (Nairobi)	7,914,218			11,005,463 (50%)
Tunisia (Tunis)	10,820,663	16,330,823 (48%)	16,133,717 (47%)	

Based on the information in Table 12, it is clear that, except for Addis Ababa and Johannesburg, the current airline networks are not organized as hub-spoke systems. African airports seem to be underutilised and a re-organization of administrative constraints and an expansion of infrastructure would likely help to create a more competitive market with lower costs. The percentages of transfer passengers could be compared to some of the major airports around the globe such as Doha (68%), Abu Dhabi (66%), Atlanta (60%) and Addis Ababa (56%) in 2013 (Maertens and Grimme, 2015). The results reach relatively high percentages of transfer passengers in some cases, in part due to the fact that we are not accounting for domestic passengers, which would decrease the transfer percentage estimates but equally increase the necessary infrastructure requirements. Consequently, the analysis should be considered relatively conservative. Furthermore, assuming a 0.7 discount factor, twelve million passengers transfer between two hubs, however under a 0.9 discount factor, the number decreases to four million. In other words, the higher the discount factor, the less cost effective is the connection between hubs.

When analysing the results for 2030, as shown in Table 13, it is clear that the African authorities should prepare for large, potential, demand flow increases as compared to the current levels.

Table 13: Passenger flows via hubs in 2030 (in parenthesis the % of transfer passengers)

	Passengers		
Country	**0.7**	**0.8**	**0.9**
Nigeria (Abuja)			53,037,856

			(72%)
Nigeria (Lagos)	56,436,999 (57%)	55,527,399 (56%)	
Ethiopia (Addis Ababa)	45,131,472 (81%)	42,895,456 (80%)	36,611,217 (76%)
Algeria (Algiers)	84,097,233 (71%)	83,376,082 (70%)	73,277,748 (67%)
Egypt (Cairo)	65,796,980 (25%)	65,326,800 (24%)	70,198,928 (30%)
South Africa (Johannesburg)	63,674,015 (32%)	59,246,098 (26%)	58,865,048 (26%)
Zambia (Lusaka)	21,500,442 (75%)	21,223,014 (74%)	20,453,123 (73%)

Whilst it is reasonable to assume that a single runway should be able to serve all airports in 2014, were demand to increase as forecasted by 2030, such infrastructure would likely be insufficient. In other words, multi-hub African carriers are free to develop across the continent according to economic considerations, all airports chosen as hubs would require at least two runways to support passenger throughput. The expected passenger flows for each of the African carriers we considered are depicted in Figures 4a and 4b and clearly identify the potential for growth. The three networks (coloured red, blue and yellow) show the potential for development of African hub-spoke network carriers at the expense of foreign airline service to some degree[5]. However, we note that the Yamoussoukro Decision or equivalent regional agreements are necessary for this type of expansion to occur.

[5] Black dotted lines represent connections with less than 100,000 passengers per year.

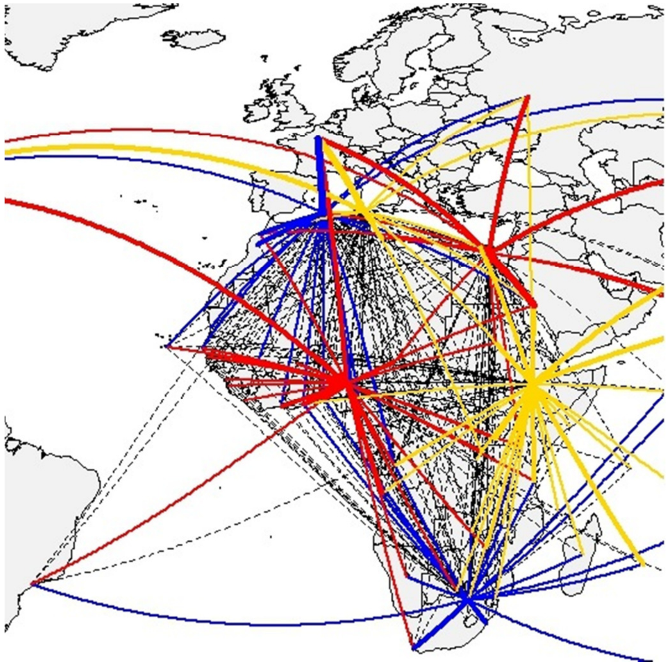

Figure 4a: Airline networks in 2014

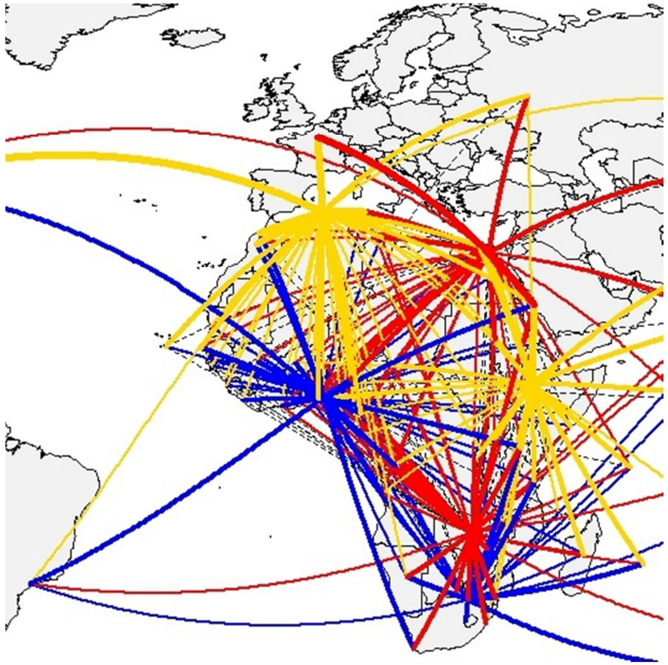

Figure 4b: Airline networks in 2030

Cairo Airport is one of Egypt's major gateways and the primary hub for flag carrier Egypt Air. With its three terminals and three runways, two of which are 4,000 m. and one of 3,180 m., the airport should be in a position to handle the growth in demand. Addis Ababa Bole Airport is Ethiopia's busiest gateway with two terminals, one dedicated to domestic operations and the other to international operations, and with two close, parallel, asphalt runways, both above 4,500 m. in length. There are ongoing discussions whether to either expand existing runway capacity or to build an entirely new airport on the western outskirts of Addis Ababa. Tambo in Johannesburg handles more than 50% of South Africa's air passenger traffic with six terminals and two parallel runways of 4,418 m. and 3,400 m. All of these airports may utilize a third runway if traffic is to increase up to 70 million passengers annually.

In Nigeria, the government has the choice to expand either of the two main airports. Currently, Murtala Muhammed Airport in Lagos has two terminals and two asphalt runways (3,900 m. and 2,742 m) whereas Abuja Airport has three terminal buildings and a single, category II runway measuring 3,600m. One or two additional runways are likely to be required at one of these airports to meet the large expected increase in demand. Algiers Airport has two runways, both of which are 3,500 m., and three terminals with a fourth expected to be completed by 2018. This infrastructure may be sufficient to meet future demand, although one of the runways may need to be extended in order to permit larger aircraft to serve the future hub. Finally, Kenneth Kaunda Airport in Zambia has a single asphalt runway of 3,962 m. and one terminal. Although the forecast arrives at more modest passenger flows of around 20 million passengers as compared to the other potential hubs, this level of infrastructure is clearly insufficient if the Zambian government wishes to strengthen their aviation supply.

It is important to note that the results of the modelling approach selected hubs on a purely economic basis. While various factors such as weather conditions and airport design (de Neufville and Odoni, 2003) may play a role in determining the choice of airports as hubs, substantial local demand has been found to be one of the main factors that airlines consider when developing hubs (Bailey et al. 1985; McShan, 1968; Bauer, 1987). Bauer (1987) argues that a city is more likely to contain a hub airport as its population and number of S&P 500 increases, or as its ranking for recreation improves. Surface access also has a significant effect on the hub decision since strong ground access is likely to increase catchment areas and ensure an airport attracts a greater number of passengers.

7. Conclusions and Future Directions

Critical to Africa's economic development is its infrastructure, which includes the air transport network. An efficient African air transport supply chain has the potential to boost intra-African trade, tourism and cultural exchanges, particularly in light of the inadequacy or lack of the continent's surface transport network. Given the geographic distances involved, African nations ought to ensure adequate airport infrastructure as a cost effective means of enabling accessibility to international markets.

The passenger traffic forecast estimates from a gravity model provide a framework specific to the African environment. Unlike the Boeing and Airbus forecasts, which are generally based on expected growth in GDP and some regional variations, the gravity model developed in this research includes additional factors such as common languages, port accessibility, corruption levels and likelihood of conflict, which are shown to have significant impact on bilateral traffic flows.

In this research, we formulate a new multi-airline *p*-hub median model, which searches for optimal hub-spoke networks by minimizing the cost of operations. The individual two-hub networks may connect a spoke to one or both hubs assuming a multiple allocation formulation. We model three hub-spoke carriers with strong economies of scale, assuming relatively substantial discount factors between hubs, up to six individual African airlines with codeshares between their hubs or slightly stronger alliance agreements, with lower discount factors across hubs. The model also accounts for inter-continental flows that may be connected with direct flights by competing foreign carriers and incorporates the existence of bilateral agreements between external and internal nodes as a constraint.

Based on the analysis of data from 2010 to 2014 and forecasted 2030 data, it is clear that the African aviation industry is being hampered by constraints including excessive government restrictions, inefficient services, high taxes, expensive infrastructure and poor safety and security. The results suggest that African governments could influence the growth of air traffic by liberalising air services, changing the rules of airline governance and reducing airport charges and fees, which are on average higher in Africa in comparison to all other regions across the globe.

Africa is a huge continent both in terms of land mass and the size of the population, expected to reach 1.679 billion by 2030. Taking both of these factors into account suggests that the air transport market could serve the continent well were the economic conditions to change.

The results of the model suggest potential hubs beyond those already serving the market, namely Addis Ababa, Cairo and Johannesburg. Our results identify Nigeria with potentially competing hubs in Abuja and Lagos, due to the large population and relative wealth of the country. Northern cities, such as Algiers and Tunis, could potentially develop hubs due to their location on the European-African flows, which represent the largest demand levels. Finally, we would argue that by 2030, there is the potential for an economically viable hub in Sub-Saharan Africa. Lusaka, the capital of Zambia, represents a prime example due to the geographic location, 17 million inhabitants and relatively higher GDP per capita in comparison to its neighbours.

Future directions include developing a game theoretic model that will enable a more accurate analysis of both airline carrier and passenger behaviour. Such a modelling approach would lead to the inclusion of airfares as a decision variable for the airlines and a discrete choice model would enable passengers to choose their flight paths based on airfares as well as route choice. Not every African country needs to be served by a home carrier, as has been shown in Europe since deregulation in 1997. The strengthening of some carriers at the expense of others will possibly create a stronger market and may lead to higher service levels across the continent. However, we also note that thin markets may require subsidies in line with the US Essential Air Services Act and the European Public Service Obligation routes. Another interesting question lies in potential competition between low cost carriers and the hub-spoke network airlines, which could also be modelled within a game theoretic framework. Finally, we have not considered the dynamics of the system and the likely impact of a gradual evolution over time from a regional perspective or as in the US case, a sudden change should the Yamoussoukro Decision be implemented across Africa simultaneously.

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