Transportation Research Part A 107 (2018) 187–202

Contents lists available at ScienceDirect

Transportation Research Part A

journal homepage: www.elsevier.com/locate/tra

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

Nicole Adler[a], Eric Tchouamou Njoya[b], Nicola Volta[c,*]

[a] *Hebrew University of Jerusalem, School of Business Administration, Mount Scopus, 91905 Jerusalem, Israel*
[b] *University of Huddersfield, Department of Logistics, Operations, Hospitality and Marketing The Business School, Queensgate, Huddersfield HD1 3DH, UK*
[c] *Cranfield University, Centre for Air Transport Management, University Way, Cranfield, Bedfordshire MK43 0TR, UK*

A R T I C L E I N F O

Keywords:
African aviation market
P-hub median
Demand forecasting
Capacity analysis

A B S T R A C T

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.

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

* Corresponding author.
E-mail addresses: msnic@huji.ac.il (N. Adler), E.Njoya@hud.ac.uk (E.T. Njoya), n.volta@cranfield.ac.uk (N. Volta).

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

https://doi.org/10.1016/j.tra.2017.11.011
Received 26 October 2016; Received in revised form 22 September 2017; Accepted 21 November 2017

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 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 $G = (N,A)$ with node set $N = \{1,2,\ldots,n\}$ 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 $EN = \{1,\ldots,f\}$, a set of internal African nodes $IN = \{f+1,\ldots,n\}$ and $\omega \in \{EN,IN\}$. 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