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Airport Classification based on Cargo Characteristics

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Abstract

Air cargo has received little attention in airport research. In this paper, 114 airports are grouped according to their cargo business characteristics. Applying a hierarchical cluster analysis, the paper uses absolute (cargo tonnage) and relative measures (share of cargo work load units, of freighter movements and of international cargo) to establish the reliance of different airport types and groupings on air cargo. Eight distinct clusters are identified which show clear differences in the characteristics of the sample with regards to cargo activities. Geographic patterns of these airports are also revealed. For example, North American and European airports are characterised by features unique to these regions. Airports that are highly dependent on air cargo tend to benefit from a central location within networks of cargo airlines, while other airports with high cargo volumes generate these as a result of significant belly-capacity of passenger operations. Understanding the heterogeneity of cargo airports is important for future benchmarking studies in this field.

1 Introduction

Airports fulfil a vital function in the air transport system by providing key infrastructure to the industry. Traditionally their (physical) output is measured by passenger numbers, aircraft movements and cargo tonnage (Graham, 2005) but also non-aeronautical service outputs (Oum and Yu, 2004). Airports Council International (ACI) identify five measures of airports' core activities; namely, passengers, origination and destination passengers, aircraft movements, freight or mail loaded/unloaded, and destinations (nonstop) (ACI, 2012). While air cargo is identified as one of the major outputs of an airport, this part of the system has received little attention in research. Graham (2005, p. 101) points out in this respect: "*Some argue that freight output is relatively unimportant since freight handling at airports is very much an airline activity and has little impact on an airport's economic performance*." For many airports and airlines, air cargo plays a minor role, but some airports heavily rely on the cargo business. For example, at Cincinnati/Northern Kentucky International Airport cargo airlines generate over 50% of the landed weights of aircraft, with DHL alone contributing to nearly 14% of the airport's operating revenues in 2013 (Cincinnati/Northern Kentucky International Airport, 2014). Current research in air transport seems to ignore the heterogeneity of airports from an air cargo perspective. While clustering or groupings of airports is common in airport research, cargo outputs play, if at all, only a minor role in the analyses (e.g. Adikariwattage et al., 2012; Malighetti et al., 2009; Rodríguez-Déniz et al., 2013; Sarkis and Talluri, 2004; Vogel and Graham, 2013). There is a strong case for classifying airports into homogenous clusters from a policy and management perspective as this leads to a better appreciation of the issues that the companies face (Malighetti et al., 2009; Rodríguez-Déniz et al., 2013). From a cargo perspective, airports are very heterogeneous, which has implications when comparing airports, managing airports and dealing with changes in the market environment. For example, Hong Kong International Airport and Memphis International Airport both registered over 4 million metric tonnes in 2013, yet cargo contributed to 41% of airport output measured in WLU (Work Load Unit = 1 passenger = 100kg of cargo) at Hong Kong, while to 90% at Memphis. All cargo at Hong Kong is international, however at Memphis over 90% is domestic (ACI, 2014). Therefore Memphis will be affected differently to changes in the market environment than Hong Kong airport.

The heterogeneity of the airport cargo business therefore results different challenges for different airports. The cargo market can be very volatile and significant regional differences with regards to growth and characteristics of air cargo can be witnessed (Morrell, 2011; Pearce, 2012). It is therefore important for airport managers and researchers to understand the core characteristics of airports and identify airports that have similar features to enable meaningful benchmarking exercises as well as identify the exposure to external influences in the cargo market, relative to other airports. Benchmarking against relevant comparator airports can help to ensure the competitiveness of an airport (Sarkis and Talluri, 2004). If wrong comparator airports are chosen, there is a danger that managers set unrealistic targets, which in turn can become difficult to achieve (Vogel and Graham, 2013). For example, benchmarking objectives can include the measurement of operating efficiency using variable factor productivities as conducted by Oum and Yu (2004). These productivities can be affected by the type of aircraft (freighter vs belly-hold) or type of cargo (e.g. domestic vs international).

The aim of this paper is to classify airports according to their air cargo characteristics to gain a better insight into their key business and reliance on air cargo. A set of airport groupings are developed that can help airport managers and researchers to develop benchmarking criteria for specific airports which have a significant cargo throughput or want to develop their cargo activities. Identifying comparator airports is a key aspect of benchmarking (Vogel and Graham, 2013) and therefore requires careful consideration.

2 Air Cargo Developments

2.1 The Air Cargo Sector

Richard Branson of Virgin Atlantic Airways describes the cargo side of air transport as "*a phenomenal industry [which] has become even more important not only to the success of airlines but also to every consumer and business leader around the world.*" (Branson, 2013, p. xvi). Air cargo, measured in freight tonne kilometres (FTK) has grown at a faster rate than global Gross Domestic Product (GDP) and passenger demand in revenue passenger kilometres (RPK) since the 1970s (IATA, 2013). However since the 2008/2009 recession there has been a reversal with air cargo first regaining pre-recession levels at a faster pace than passenger demand, but then stalling and showing no growth from 2010 to 2013. Passenger markets at the same time started to grow in this period. This means that while in 2004, air cargo contributed to about 30% of airlines' output measures in RTKs (Revenue Tonne Kilometres), in 2013 this number declined to about 25% (ICAO Data+, 2014; IATA, 2014a). For airports, globally, the output measured in WLUs was about 14% (ACI, 2014).

While the cargo side of air transport is relatively small in comparison to passenger traffic, it is of importance to airlines, airports and the wider economy. In 2012, worldwide airline net profits accumulated to USD 2.56 per departing passenger while cargo and other revenue generated USD 34.26 per departing passenger (IATA, 2013). Given the low net profit margin of airlines, this illustrates that cargo revenues can create an important contribution to airlines' profitability.

Air cargo developments are closely linked to general economic development. Air cargo and GDP development are highly interdependent with air cargo development usually preceding GDP growth (Kasarda and Green, 2005). This has also been recognised after the 2008/2009 recession with air cargo initially improving before GDP recovered. The underlying reasons being companies restocking their production and retail operations to cater to the expected and recognised recovery (Pearce, 2012). Furthermore there is some evidence that supports the idea that air cargo operations positively affect regional economic development (Button and Yuan, 2013).

The growth of a global transport infrastructure (with air cargo being an important component) supports the development of global supply chains, which sees production facilities geographically removed from demand, which has led to an international fragmentation of production and consumption (Christopher, 2005; Zhang, 2003). This has resulted in the development of "global supply chain management centres" (GSCMC), which are not only characterised by the physical aspects of logistics but include also the relevant knowledge base (Wang and Cheng, 2010). Logistics functions, including airports, are therefore often geographically concentrated (Hesse and Rodrigue, 2004). Although there are established logistics and transportation clusters, these are not static. For example, in China, new logistics clusters in Chengdu, Chongqing and other cities further west and north of the traditional logistics centres of Shanghai, Beijing and in the Pearl River Delta are emerging (A. T. Kearney, 2010). This can also be witnessed at airports in these cities, with Chengdu and Chongqing attracting more airlines and growing their cargo volumes (CAPA, 2013a).

In 2013, just over half of scheduled worldwide cargo was transported on cargo-only aircraft with the remainder in the belly hold of passenger planes (IATA, 2014c). However forecasts show that the share of belly hold cargo is likely to increase in the coming years as particularly the cargo-carrying capacity of wide-body passenger aircraft has created new opportunities for airlines (IATA, 2014c). For example the Boeing 777-300ER can hold 18% more cargo volume than the 747-400 (CAPA, 2013b).

Although the role of air cargo has changed over the last few years, with increasing competition from other modes, particularly maritime transport, many industries are highly dependent on air cargo. Also the different organisations in the air transport industry are reliant on air cargo with many airlines and airports generating a large amount of revenue or physical output (RTKs/WLUs) from these business activities.

2.2 Air Cargo and Airports

Airports are an important link in the air cargo system that provide the interface between surface transport and activities and aircraft operations (Morrell, 2011). Despite airports' importance in the system, traditionally they are often seen as an "external medium" rather than being integrated in supply chains, yet some change towards more enhanced services can be recognised (Jarach, 2001). While most airports in the world are small regional airports that see little cargo throughput, other airports are highly dependent on air cargo operations (Sale, 2013), e.g. Memphis International Airport or East Midlands Airport. When identifying the importance of air cargo for airports, the differences between cargo and passenger throughput among the top ten airports globally become apparent. In 2013, only two of the top ten cargo airports (Dubai International Airport and Paris-Charles de Gaulle) are also in the top ten for passenger throughput (Table 1).

Global Rank	Top 10 Airports by Total Cargo	Million Metric Tonnes	Top 10 Airports by Total Passengers	Million Pax
	Airport		Airport	
1	Hong Kong International Airport (HKG)	4.2	Hartsfield-Jackson Atlanta International Airport (ATL)	94.4
2	Memphis International Airport (MEM)	4.1	Beijing Capital International Airport (PEK)	83.7
3	Pudong International Airport (PVG)	2.9	Heathrow Airport (LHR)	72.4
4	Incheon International Airport (ICN)	2.5	Tokyo Haneda Airport (HND)	68.9
5	Dubai International Airport (DXB)	2.4	O'Hare International Airport (ORD)	66.8
6	Ted Stevens Anchorage International Airport (ANC)	2.4	Los Angeles International Airport (LAX)	66.7
7	Louisville International Airport (SDF)	2.2	Dubai International Airport (DXB)	66.4
8	Flughafen Frankfurt/Main (FRA)	2.1	Aéroport de Paris-Charles de Gaulle (CDG)	62.1
9	Aéroport de Paris-Charles de Gaulle (CDG)	2.1	Dallas/Ft Worth International Airport (DFW)	60.5
10	Narita International Airport (NRT)	2.0	Soekarno-Hatta International Airport (CGK)	60.1

Table 1: Top 10 Airports by Cargo and Passengers 2013
Source: ACI, 2014

Air cargo throughput among the top airports is also more concentrated than passenger numbers. Logistics functions, be it airports, ports or distribution centres, are frequently focussed on a few strategic locations with high flows through these nodes which is often fuelled by regional specialisation (Alkaabi and Debbage, 2011; Hesse and Rodrigue, 2004). For example, the top 15 cargo airports account for about 40% of the cargo tonnage of the 150 largest cargo airports while on the passenger side, the 15 top passenger airports only make up 20% of the passenger numbers at the top 150 passenger airports (ACI, 2014). This concentration is also recognisable in individual air transport markets. For example in the United States (US) air cargo is focussed on a few large hubs. Drivers for this concentration can be mainly found in the large integrators like FedEx and UPS (Alkaabi and Debbage, 2011).

Many facilities that are required for passenger operations are also supporting cargo operations, but in addition air cargo requires storage facilities, handling equipment and access to major trunk roads (Morrell, 2011). For example in the United Kingdom, East Midlands Airport (the country's second largest cargo airport) benefits from easy access to the M1 motorway that links London with the North East of England.

Airports act as nodes in air transport for three flows in the air cargo system. Firstly, local air cargo aimed for domestic consumption and catering for exports from the local area passes through the airport. Secondly, airports act as gateways, with cargo generated or destined for the manufacturing sector in the airport's hinterland, passing through the airport. Finally, airports function as transhipment hubs for "hub cargo", i.e. air-to-air flows that are loaded from one aircraft to another with a destination outside the immediate region of the airport. Different airports have different shares of these elements of air cargo and different priorities. For example at Hong Kong airport, gateway traffic dominates while at Singapore airport "hub cargo" is prioritised (Zhang, 2003). Other airports that focus on transhipment cargo are Anchorage, Doha, Abu Dhabi and Dubai which all benefit from their respective geographic location (Boquet, 2009). The focus of airports with regard to air cargo therefore often depends on their geographic position, manufacturing base, as well as airlines operating at the airport.

Addressing the use of airports by air cargo operators, Morrell (2011) points out that integrators usually prefer secondary airports, characterised by low passenger numbers and little congestion while network airlines are driven by their passenger operations (i.e. combining passenger and cargo operations in one location). The focus of non-integrated carriers on major airports has been identified by Gardiner and Ison (2008), with many combination carriers aiming to co-locate passenger and cargo operations. Identifying the role of secondary airports in air cargo, Boquet (2009) aligns UPS's US network strategy to the network strategy of low-cost airlines, i.e. creating regional hubs at secondary airports near major cities. Furthermore, secondary airports often are located close to distribution centres (Bowen, 2012). Referring to integrators, Alkaabi and Debbage (2011p. 1521) argue that "*both FedEx and UPS have operated the bulk of their network out of a small number of medium-sized metropolitan markets that feature a combination of either surplus airport capacity, a business-friendly environment and/or were strategically located in the center of the country*." Market centrality, i.e. hubs centrally located in traffic-generating regions, is a key aspect in integrators' network development (Bowen, 2012). Accessibility and geographic location have been a major factor for the growth of cargo at airports. Airports like Indianapolis in the US and Amsterdam in Europe are examples of airports that have seen significant volumes of cargo thanks to their geographic location and accessibility (Hesse and Rodrigue, 2004).

Cargo activities have a range of impacts on airports' performance. The share of cargo as an airport's output has a positive effect on gross variable factor productivity (VFP), with airports handling larger proportions of cargo achieving higher levels of gross VFP. The underlying reason for this is that cargo requires less input than passenger operations (Oum and Yu, 2004). Understanding the role that cargo plays at airports (as measured by the traffic share) can therefore be of relevance to airports and air transport researchers. So far, cargo traffic shares have not featured in research and cluster analyses of airports while absolute values are sometimes featured in papers such as Oum and Yu (2004) and Sarkis and Talluri (2004).

Airlines, both combination carriers and integrators have adjusted their cargo network over time. While for example integrators have increased the number of global hubs and moved into new markets, some hubs have been downgraded or moved to other airports. Underlying reasons for the changes are economic downturns (e.g. Dallas-Ft. Worth/UPS), economic growth in other regions (e.g. Subic Bay/FedEx), and night time restrictions (e.g. Frankfurt/FedEx) (Bowen, 2012). Environmental restrictions can severely impact airports' ability to develop cargo activities and airports that are not affected by these restrictions can benefit from limitations at other airports. For example, Leipzig/Halle Airport benefited from stricter environmental rules at Brussels National Airport. The former experienced a significant increase in tonnage from 2005 to 2013, while the Belgian airport saw its cargo tonnage nearly halved from 2007 to 2009 (Figure 1). The main reason for the change at the two airports was the relocation of DHL's hub in Brussels to Leipzig/Halle: "*In 2005, Deutsche Post decided to build a new hub in Germany, in the heart of Europe, because night-flight operations could not be expanded at the existing DHL hub in Brussels.*" (DHL, 2008).

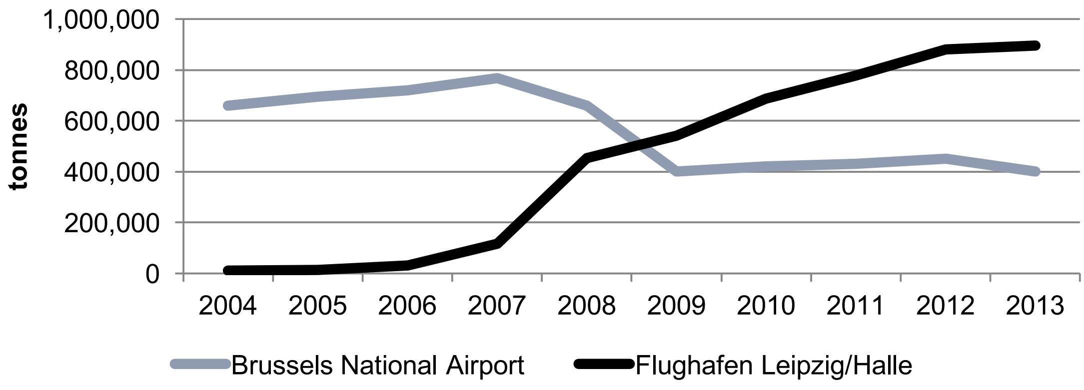

Figure 1: Cargo Tonnes at Brussels and Leipzig/Halle
Source: Eurostat, 2014

Whereas night operations capabilities are important for integrators, this is less the case for combination carriers (Gardiner and Ison, 2008). Therefore the requirements of airlines with regard to the airport offerings will vary depending on the airline business model.

Previous research has identified the role and importance of air cargo in the air transport system (e.g. Alkaabi and Debbage, 2011; Bowen, 2012; Button and Yuan, 2012; Hesse, 2014; Kasarda and Green, 2005; Yuan et al., 2012). The focus in research is often on the passenger side of the industry with air cargo being seen as an add-on or by-product. Yet by looking at air cargo at airports in more detail, differences between the airports in volume, characteristics and developments can be identified. This paper will provide an analysis of these characteristics beyond total cargo volumes and changes in volumes by classifying airports according to absolute and relative cargo volumes, the percentage of freighter movements and international cargo. Thus, airports with similar cargo characteristics will be identified and grouped.

2.3 Airport Classification

The classification of airports is common in air transport research and previous research has shown the necessity and appropriateness of grouping airports according to common characteristics (e.g. Adikariwattage et al., 2012; Malighetti et al., 2009; Rodríguez-Déniz et al., 2013; Sarkis and Talluri, 2004; Vogel and Graham, 2013). The focus of the research on airport classifications varies with different aims and approaches. A key theme is the use of groups in benchmarking exercises (Adikariwattage et al., 2012; Oum and Yu, 2004; Sarkis and Talluri, 2004; Vogel and Graham, 2013).

Classifications so far are mainly based on size of airports (including cargo tonnage), geographic position, functional role, nature of traffic, utilisation and technical characteristics, ownership and network position (Adikariwattage et al., 2012; Malighetti et al., 2009; Vogel and Graham, 2013). However, airport classification has mainly included passenger-related variables. For example Adikariwattage et al. (2012) use the number of gates, annual volume of international and domestic transfer and origin-destination passengers to cluster US airports. Malighetti et al. (2009) include variables related to passenger connectivity (e.g. number of seats available, number of destinations serviced, distribution of traffic among routes etc.) in their cluster analysis of European airports. Rodríguez-Déniz et al. (2013) base their airport cluster analysis on airline ticket data (i.e. passenger data) in the US. While there is a strong focus on passenger related segmentation of airports, some studies include cargo-related variables. For example, Sarkis and Talluri, 2004 use cargo tonnage in their study. In this case, total values (i.e. cargo tonnage) rather than partial values (e.g. cargo output as percentage of the total output) are used. Vogel and Graham (2013) use performance and efficiency ratios (e.g. Total revenue/WLU or Cash flow as % of revenue) as cluster variables. While WLUs include cargo output, this often only shows a fraction of the cargo business, particularly at airports that are dominated by passenger traffic. Also by combining the passenger and cargo output, cargo characteristics tend to be lost due to the greater focus on the passenger business.

As shown above, there are numerous studies that use quantitative techniques to classify airports by passenger characteristics, yet when it comes to cargo-focussed studies, these classifications are mainly based on qualitative analyses. ACI (2010) identifies the “Freight Platform” as one of eight emerging new business models for airports in Europe, referring to Liège and Leipzig/Halle as examples for this business model. While the ACI report identifies the “Freight Platform” as an “*airport specifically catering to the needs of freight operators*” it does not elaborate on what these needs are and how airports address them. Furthermore it ignores the range of different airports that cater for the air cargo community, with some of the largest cargo airports also playing a significant role in passenger networks. Similarly to the ACI classification, Jarach (2001) uses a qualitative approach in grouping airports according to their market positioning with cargo airports being one of five possible market positionings. Jarach (2001, p. 121) defines cargo airports as airports that "*target cargo operators and integrators as its own core business. The site has a wide number of technical infrastructures for cargo business operations.*" Jarach's (2001) groups show that positionings are not mutually exclusive by labelling Paris CDG as an example of a "primary hub" and a "cargo airport". Jarach (2001) addresses market positionings of airports, i.e. takes an apriori approach by first identifying types of airports and then allocating examples to each positioning. However, no metrics or further discussion of how airports can be matched to these positionings is provided. Neiberger (2008) classifies cargo airports into three groups: international nodes (major hubs); airports with high freight volumes (i.e. between ca. 200,000 and 600,000 tonnes); and airports which act as feeders to hubs. However this classification lacks a more robust scientific methodology as well as practical usefulness. For example it groups airports such as Liège and Munich in the same category. These two airports have very distinct and different cargo characteristics and therefore researchers and practitioners will find it difficult to use this classification to identify comparator airports. Alkaabi and Debbage (2011) identify three types of cargo airports in the US market: "Integrated all-cargo carrier hub", "traditional passenger connecting hubs" and "international gateways". These groups are also classified based on qualitative characteristics related to the airlines that operate at these airports rather than quantitative variables related to the airports' output and characteristics.

This paper will address shortcomings in the literature, by developing global clusters of airports, based on quantitative characteristics from the cargo market. This will enable airport managers and researchers to clearly identify airports with similar, and measurable, characteristics in their cargo output for benchmarking exercises, policy and management decisions (e.g. how and what airports are affected by changes in the market environment).

3 Data and Methodology

3.1 Airport Sample

The data for this research is drawn from ACI's 2013 World Airport Traffic Report. Initially the top 150 global airports by passenger numbers, cargo tonnage and air transport movements were included in the airport sample. This results in a sample of 196 airports. However, a frequent problem in air cargo research is the unavailability of data (e.g. Kalakou and Macário, 2013). Of the 196 airports, only 114 airports provide a full data set that can be used in the cluster analysis. A list of the 114, sorted by IATA code, can be found in Appendix A. The sample comprises a mixture of 35 European (EUR), 35 North American (NAM), 22 Asia-Pacific (PAC), 11 Latin American and Caribbean (LAC), 7 Middle Eastern (MEA) and 4 African (AFR) airports. The sample consists of about 70% of the global cargo tonnage reported in the ACI World Airport Traffic Report. Few studies comprise of a global airport sample (e.g. Oum and Yu, 2004; Vogel and Graham, 2013), with many either focussing on a particular region, e.g. the United States (Adikariwattage et al., 2012; Alkaabi and Debbage, 2011; Rodríguez-Déniz et al., 2013; Sarkis and Talluri, 2004), particular airports (e.g. Hesse, 2014; Zhang, 2003) or hubs of particular carriers (e.g. Bowen, 2012). Of the two global studies, the number of airports in the sample included 90 and 73 airports respectively, while regional studies often have larger samples. For example Malighetti et al. (2009) in their classification of European airports group 467 airports, while Adikariwattage et al. (2012)

cover 209 US airports. In comparison to other research, this paper covers a large sample of international airports, giving a comprehensive global overview of the key characteristics of airports from a cargo perspective.

3.2 Cluster Analysis

In this paper, airports are grouped with regards to their cargo characteristics. Cluster analysis is a commonly used approach in airport research to classify airports (e.g. Adikariwattage et al., 2012; Malighetti et al., 2009; Rodríguez-Déniz et al., 2013; Sarkis and Talluri, 2004; Vogel and Graham, 2013). Cluster analysis is a statistical method for classifying groups (Punj and Stewart, 1983). Hierarchical clustering is particularly popular in classifying airports, as applied by Malighetti et al. (2009), Rodríguez-Déniz et al. (2013), Sarkis and Talluri (2004), and Vogel and Graham (2013). Rodríguez-Déniz et al. (2013, p. 191) highlight one of the key benefits of hierarchical clustering over *k*-means clustering: "(…) *hierarchical classification is typically presented in a tree-like diagram (i.e. dendrogram) that provides a more informative structure than the flat clusters obtained from other partitioning methods such as k-means.*" In this paper, Ward's method is selected as the applied agglomerative algorithm using squared Euclidean distance as distance measurement. Ward's method is frequently used in transport related cluster analyses (e.g. Anable, 2005; Davison and Ryley, 2010; Malighetti et al., 2009; Martinez-Garcia and Royo-Vela, 2010; Vogel and Graham; 2013). As distance measure, squared Euclidean distance is the recommended and most used form when using Ward's method (Burns and Bruns, 2008; Hair et al., 1998; Norušis, 2011).

Based on the aim of this paper, four variables relating to the air cargo output of airports are chosen to be included in the cluster analysis; these are:

1. Total cargo throughput (in metric tonnes) per annum (p.a.)
2. Cargo work load units (WLUs) as a percentage of the total WLUs
3. Freighter aircraft movement as a percentage of all commercial aircraft movements
4. International cargo as a percentage of the total cargo volume

The variables are chosen to measure the total cargo output of the sample airports, therefore the importance of the airport relative to other airports and to measure the relative importance of air cargo for an airport. This is both with regards to volumes as well as freighter movements. While freighter movements do not take into account belly-hold cargo (i.e. cargo transported on passenger aircraft), freighter operations have significant impacts on the cargo management at airports as well as unique requirements. The freighter share at an airport has an impact on how airports manage their cargo operations (Gardiner et al., 2005). The final variable, Variable 4, represents the share of international cargo at the airport. International cargo creates different challenges to domestic cargo, particularly when it comes to customs, agricultural and security inspections. While there are other variables that can affect air cargo at airports, these provided little further insight when they were included in the analysis (e.g. number of runways, runway length) or are difficult to measure (e.g. operational restrictions such as night curfews) and are therefore not included in the clustering process.

Distance measures in cluster analyses are susceptible to differing scales and levels of variables (e.g. absolute values vs. percentages) (Norušis, 2011). Therefore, based on the variables used in this research, standardisation (i.e. converting data into standard scores with a mean of 0 and a standard deviation of 1) of the values is necessary to make sure that all variables have similar effects on the distance measurement (Hair et al., 1998; Norušis, 2011).

Hair et al. (1998) suggest adopting an iterative approach (i.e. trial of different solutions) which is applied to determine the most appropriate number of clusters. Additionally, a dendrogram (Appendix B) and agglomeration schedule is used to identify possible cluster solutions. Several possible numbers of clusters are trialled. Although the dendrogram and agglomeration schedule indicate several options from five to ten clusters, eventually an eight-cluster-solution produced the most appropriate division of the airports in the sample. This solution allows for a more differentiated assessment of the airports from a cargo perspective, particularly with regard to the different international focus of the airports. A larger number of clusters would mainly impact on the less cargo-focussed airports while a smaller number of clusters would lose key characteristics of the cargo-dominant airports with regards to their share of international freight.

4 Findings

4.1 Overview

As mentioned previously, the cluster analysis produced eight clusters. The dendrogam shown in Appendix B, highlights the eight clusters and shows that particularly Clusters 1 and 2 as well as Clusters 3, 4 and 5 are different to Clusters 6, 7 and 8. The results of the cluster analysis can be found in Table 2. Table 2 shows that the first four clusters are relatively small with two, three and five airports in each cluster respectively. Despite being relatively small clusters, they all show distinct characteristics that separates them from the other clusters. Together with the larger Cluster 5, these first five clusters show a higher importance of air cargo than the remaining groups. While these 30 airports represent 26.3% of the airports in the sample, they account for 72.4% of the cargo throughput of the 114 airports. As previous identified in the literature review, this shows the high concentration of air cargo at certain airports.

The eight clusters have been labelled as follows:

- Cluster 1: Cargo-dependent Europeans
- Cluster 2: North American Cargo Primaries
- Cluster 3: European Dual-Bases
- Cluster 4: North American Cargo Secondaries
- Cluster 5: International Primary Hubs
- Cluster 6: International Secondary Hubs
- Cluster 7: Passenger Dominant Airports (International)
- Cluster 8: Passenger Dominant Airports (Domestic)

As shown in Table 2, and also identified by the some of the cluster labels, there are strong geographic associations among the groups with four clusters (1, 2, 3 and 4) only representing airports from one region respectively and one cluster (6) containing airports from all regions apart from North America. Furthermore, Cluster 8 predominantly contains US and Chinese airports. This illustrates that there are significant regional differences between airport clusters and therefore cargo characteristics, particularly when looking at

European and North American Airports. Figures 2, 3 and 4 highlighting the graphic locations of Clusters 1 to 5, i.e. those airports that are more cargo-focussed.

Cluster	Cluster 1	Cluster 2	Cluster 3	Cluster 4	Cluster 5	Cluster 6	Cluster 7	Cluster 8
	Cargo-dependent Europeans	North American Cargo Primaries	European Dual-Bases	North American Cargo Secondaries	International Primary Hubs	International Secondary Hubs	Passenger Dominant Airports (International)	Passenger Dominant Airports (Domestic)
No of Airports	2	3	3	5	17	42	15	27
Airports	LEJ	ANC	CGN	CVG	AMS	AKL	CUN	AUS
	LGG	MEM	EMA	IND	BKK	ARN	DFW	BDL
		SDF	LUX	OAK	CAN	ATH	DME	BOS
				ONT	CDG	AUH	DMK	CJU
				YWG	DXB	BGY	EWR	CKG
					FRA	BOG	GRU	CLE
					HKG	BRU	IAD	CLT
					ICN	CAI	IAH	DEN
					JFK	DOH	LED	GMP
					LAX	DUS	NCE	HGH
					LHR	EZE	PER	HOU
					MIA	FCO	SFO	LAS
					NRT	GDL	SVO	MCI
					ORD	GVA	TSN	MCO
					PVG	HAM	YYZ	MSP
					SIN	JNB		NKG
					TPE	KIX		PDX
						LGW		PHX
						LIM		SAN
						LIS		SEA
						LOS		SLC
						MAN		THR
						MCT		TPA
						MDE		VKO
						MEX		WUH
						MUC		XIY
						MXP		XMN
						NBO		
						NGO		
						ORY		
						OSL		
						PTY		
						SAW		
						SCL		
						SHJ		
						STN		
						TLV		
						TXL		
						UIO		
						VIE		
						WAW		
						ZRH		
Region								
AFR						4		
PAC					8	3	3	8
EUR	2		3		4	21	4	1
LAC						9	2	
MEA					1	5		1
NAM		3		5	4		6	17

Table 2: Airport Clusters

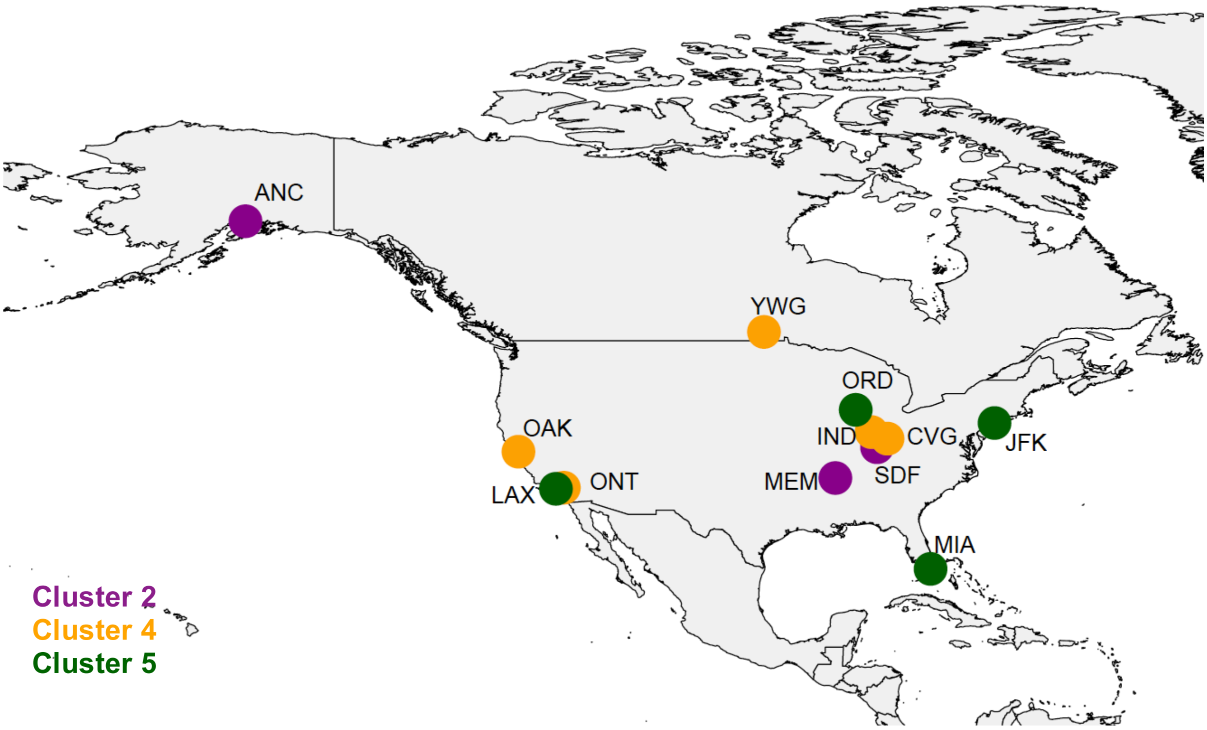

Figure 2: Airports in North America

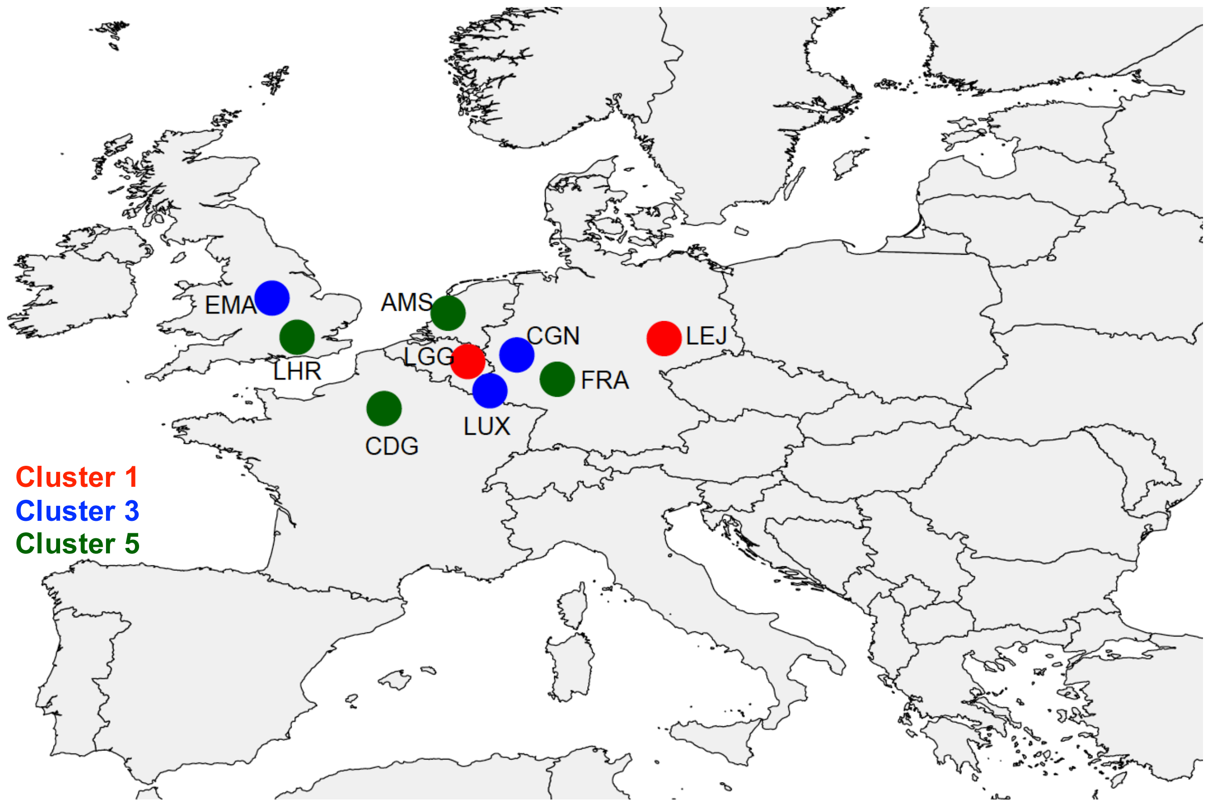

Figure 3: Airports in Europe

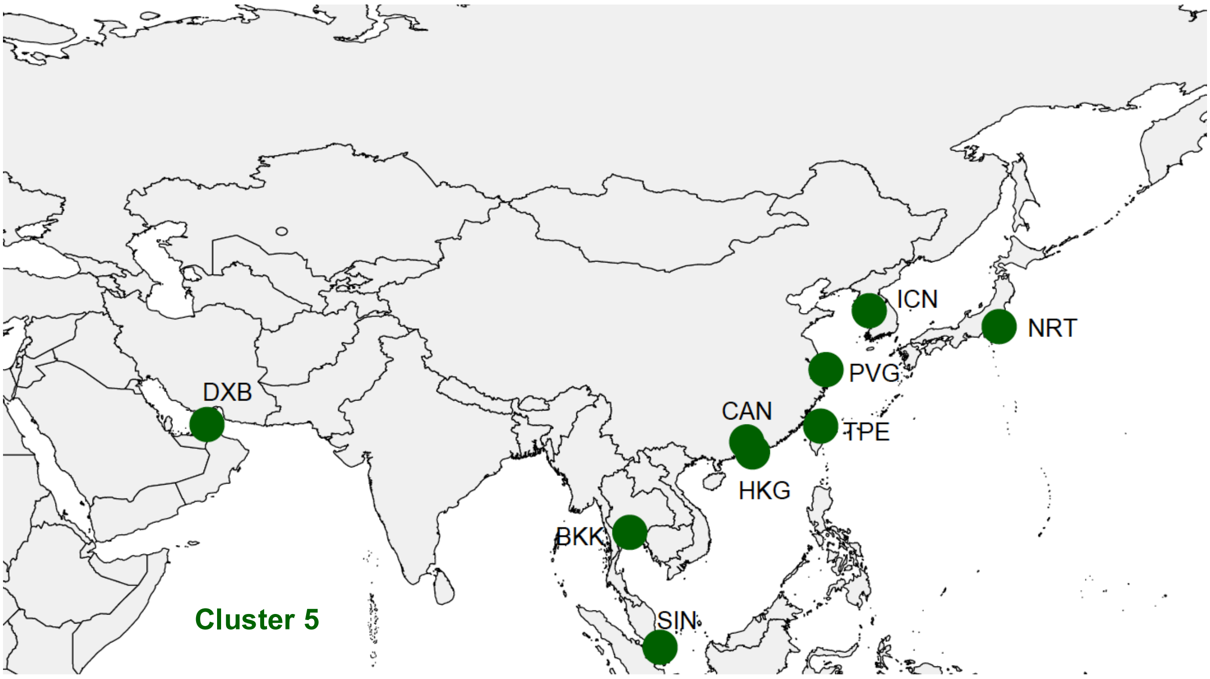

Figure 4: Airports in Asia

The means (cluster centres) for each variable used in the clustering process are given in Table 3 and show the key characteristics of each cluster. A Kruskal-Wallis test was conducted which supports that there are statistically significant differences in the four variables between the eight clusters ($p < 0.05$).

	Cluster 1 Cargo-dependent Europeans	Cluster 2 North American Cargo Primaries	Cluster 3 European Dual-Bases	Cluster 4 North American Cargo Secondaries	Cluster 5 International Primary Hubs	Cluster 6 International Secondary Hubs	Cluster 7 Passenger Dominant Airports (International)	Cluster 8 Passenger Dominant Airports (Domestic)
Cargo Tonnes p.a.	719,592	2,925,008	563,049	531,445	1,969,389	232,068	275,725	164,112
Share Cargo WLU (%)	87.50	86.67	53.33	45.20	27.00	12.74	8.20	7.48
Share Freighter Aircraft of Air Transport Movements (ATM) (%)	73.00	50.00	27.67	19.00	6.65	4.05	2.20	2.4
Share International Cargo (%)	96.50	32.00	94.00	11.20	89.12	94.05	58.20	10.44

Table 3: Cluster Centres

The table shows that Clusters 1 and 2 are most reliant on cargo measured by the percentage of WLUs at the airports, while Clusters 2 and 5 see the highest cargo tonnage. In the case of Cluster 1, this dependency not only relates to the share of WLUs but also to the share of freighter movements at the airports. Clusters 6, 7 and 8 are least dependent on cargo, both in absolute (tonnage) as well as in relative terms (percentage of WLUs and freighter movements). The importance of international cargo varies between the airports, with clusters that are dominated by US airports showing the lowest share of international cargo. As expected, countries with a large land mass (notably the US and China) record a higher share of domestic air cargo while particularly smaller countries in Europe, based on their size, have a high volume of international cargo.

In a next step, cluster profiles are developed. Profiling relates to identifying the characteristics of the clusters using variables that have not previously been included in the clustering process. In profiling this is taken a step further to describe, rather than determine the clusters (Hair et al., 1998). A Kruskal-Wallis test performed on variables not used in the clustering process (Table 4) shows that there are statistically significant differences between the airports groupings ($p < 0.05$). The analysis supports the claim that there is also external validity to the performed cluster analysis. Clusters do not only vary according to the variables used in the cluster analysis but also between variables that have not been used in the clustering process.

Table 4 highlights that, apart from the International Primary Hubs, cargo focussed airports (Clusters 1-4) are characterised by lower numbers of passengers in comparison to those airports where cargo is of minor importance (Clusters 6-8). This suggests that for these airports there is a trade-off between cargo and passenger focus. Furthermore, the cargo dependent airports show a lower number of air transport movements than the passenger focussed airports, however the North American airports (Clusters 2 and 4) show a higher number than their European counterparts (Clusters 1 and 3). Similarly certain clusters that are dominated by North American airports, have a lower share of international passengers. Given that a large proportion of cargo is transported in the belly-hold of passenger planes, there is a strong, and statistically significant, correlation between the share of international passengers and international cargo at airports ($r_s = 0.92$, $p < 0.05$). As expected, cargo focussed airports show a higher cargo tonnage per air transport movement (ATM) (given the higher share of freighter aircraft movements). This is particularly noticeable for the highly cargo-dependent airports in Clusters 1 and 2 and to a lesser extent in Clusters 3, 4 and 5 as these airports also have a significant share of passenger traffic. The higher share of passenger traffic is also noticeable in the number of passengers per ATM, which is significantly lower for cargo-dependent airports than for others.

	Cluster 1	Cluster 2	Cluster 3	Cluster 4	Cluster 5	Cluster 6	Cluster 7	Cluster 8
Cluster	Cargo-dependent Europeans	North American Cargo Primaries	European Dual-Bases	North American Cargo Secondaries	International Primary Hubs	International Secondary Hubs	Passenger Dominant Airports (International)	Passenger Dominant Airports (Domestic)
Air Transport Movements (ATM)								
Mean	40,845	179,485	72,536	107,113	403,878	158,157	277,384	232,288
SD	21,360	37,827	30,444	31,590	152,447	76,047	164,535	133,219
Total Passengers (million)								
Mean	1.27	4.44	5.21	6.03	53.41	17.19	27.68	22.74
SD	1.36	0.90	3.52	2.55	11.77	8.40	14.66	12.24
Share International Passengers (%)								
Mean	81.00	0.33	86.00	5.00	72.94	71.00	39.40	7.26
SD	18.39	0.58	17.06	7.42	31.93	24.06	20.00	8.83
Cargo Tonnes per ATM								
Mean	18.75	16.29	8.33	4.89	5.55	1.72	0.96	0.82
SD	4.32	4.21	4.40	2.12	2.78	1.44	0.68	0.47
Passengers per ATM								
Mean	26.00	24.75	66.91	56.00	139.71	109.29	103.87	99.93

SD	19.71	0.84	21.18	14.71	27.95	20.40	19.26	23.87

Table 4: Cluster Profiles

Besides the 2013 data, the same cluster analysis was conducted with data from 2005 (though with a smaller number of airports due to data availability). Generally, it can be noted that the cargo-focussed clusters (particularly Clusters 1, 2 and 4) are fairly stable over time. In 2005, Cluster 1 only consists of Liège, which is expected as the shift towards air cargo at Leipzig/Halle only came with the arrival of DHL in 2008. Cluster 2's 2013 composition is exactly the same as in 2005, while Cluster 3 (and some extent Cluster 4) has become more (cargo-)specialised and smaller with regards to the number of airports in this cluster. This comparison with 2005 shows that there is some stability in the clusters but also that there is a concentration of air cargo at fewer, more specialised airports.

In the next sections, the eight clusters will be analysed and their key characteristics presented.

4.2 Cluster 1: Cargo-dependent Europeans

Cluster 1 is the smallest of the eight clusters and consists of two European airports, namely Liège and Leipzig/Halle. Both airports are highly dependent on air cargo, both with regards to the cargo share of the WLUs as well as freighter movements. As a result, this cluster is labelled "*Cargo-dependent Europeans*". While in total volumes these two airports are significantly smaller than major US cargo airports or the main European passenger hubs, they are among the larger European airports measured by cargo tonnage. This results also in a very high amount of cargo per air transport movement. The majority of cargo at these airports is international, which particularly in the case of Liège is based on the small size of Belgium and therefore insignificant domestic air transport operations. Both airports are the major hubs of two European logistics companies, TNT Express (Liège) and DHL (Leipzig/Halle), where both companies base their airline subsidiaries. Geographic location and operating conditions have played an important role in the airlines' decision to set up the centre of their air operations at these airports (DHL, 2008; TNT, 2011). While Liège benefits from a strategic location between the European major economic centres of Amsterdam, Paris and Frankfurt (Kalakou and Macário, 2011), Leipzig/Halle benefits from its close proximity to emerging economies in Central and Eastern Europe (Hesse, 2014). Whereas Liège and Leipzig/Halle are relatively homogenous from a cargo perspective, it can be noted though, that they are quite diverse when taking into consideration passenger operations (i.e. 0.3m vs 2.2m passengers p.a.). Both airports have two runways (though in the case of Liège they are not independent parallel runways and one is under 2,400 metres), which creates significant airside capacity (Flightglobal, 2015; Adler and Liebert, 2014). Besides the high share of air cargo at these airports, the large airside capacity and its reliance on air cargo to fill this capacity make these airports vulnerable to changes in the cargo market.

4.3 Cluster 2: North American Cargo Primaries

Cluster 2 consists of three US airports: Memphis, Louisville and Anchorage. This cluster is labelled "*North American Cargo Primaries*" as these airports are the three largest airports in North America measured by cargo tonnage. Furthermore these airports are among the ten largest cargo airports globally, with over 2 million tonnes of cargo p.a. for Anchorage and Louisville and over 4 millions tonnes for Memphis. While Memphis and Louisville are the primary hubs of FedEx and UPS respectively, Anchorage is a hub for both companies. For

FedEx the link Memphis – Anchorage and for UPS the route Louisville – Anchorage are among the busiest routes, stemming from their roles as hubs in a continental and international hub-and-spoke system (Bowen, 2012). Resulting from the high volumes of cargo at these airports, the share of cargo as a percentage of the total WLU is also very high, with an mean share of 86.67%. This is similar to Cluster 1, however the share of freighter aircraft is significantly lower for the North American airports, particularly for Anchorage, as passenger traffic, mainly regional traffic, contributes to the North American airports' output. Also the share of international freight is lower for these airports, yet Anchorage, based on its location on the Pacific Rim, connecting Asia and North America, has a larger share than the other two airports. For all three airports, centrality is a key factor in air cargo flows. In the case of Louisville and Memphis the centrality is within the (Eastern part of the) contiguous US and in the case of Anchorage its position between Asia and other US and Canadian airports (Boquet, 2009; Bowen, 2012). While air cargo dominates at these three airports, passenger numbers are sizable too, with a mean of 4.44m passengers p.a., which is significantly larger than the two European cargo hubs in Cluster 1.

As a share of their operations, air cargo is the major business activity of the North American Cargo Primaries, but passenger operations in total terms are important too. Yet similar to the European companies, these airports are dependent on particular integrators and express cargo operators.

4.4 Cluster 3: European Dual-Bases

In Cluster 3, three European airports are grouped: Cologne/Bonn, East Midlands and Luxemburg. These airports are hubs for cargo operators as well as passenger airlines and therefore fulfil a dual function covering both major air transport outputs. As such, this cluster is labelled "*European Dual-Bases*", recognising their hub/base function in cargo and passenger operations. Cologne/Bonn is a European hub for both UPS and FedEx as well as a base for Germanwings and Ryanair (Germanwings, 2015; FedEx, 2014; Ryanair, 2014; UPS, 2014). East Midlands hosts cargo operations by DHL, UPS and TNT as well as being a base for Ryanair, Jet2 and Thomson Airways (Dart Group, 2015; East Midlands Airport, 2015; Ryanair, 2014), while Luxemburg is the hub for CargoLux and Luxair (Luxair, 2014). Similar to other airports that focus on cargo operations, the airports in this cluster also benefit from their geographic location. Luxemburg and Cologne/Bonn (similarly to Liège) are centrally located in Western Europe, with Cologne/Bonn additionally being situated in the Rhine-Ruhr metropolitan region. Similarly, East Midlands is centrally located in England, between London and the Liverpool-Manchester-Leeds-Sheffield corridor as well as closely situated to Birmingham. Airports in this cluster, mainly register international cargo rather than domestic cargo, which is a key characteristic of European airports (similar to Cluster 1). While the average cargo volume for this cluster is similar to Cluster 1, the share of cargo as a percentage of the WLUs and the share of freighter aircraft is smaller. Therefore, despite their focus on air cargo, they are less exposed to changes in the cargo market as passenger operations are also an important part of the business model.

4.5 Cluster 4: North American Cargo Secondaries

In Cluster 4, five North American airports (four US and a Canadian airport) are grouped. This cluster shares many characteristics with the "European Dual-Bases", particularly with regards to average cargo throughput in tonnes, share of cargo WLUs and annual passengers. These airports have a smaller share of freighter movements than the European airports and the share of international cargo is significantly smaller in this cluster (similar to the North American Cargo Primaries). Cargo operations are important for these airports as about half of their output (measured in WLUs) stems from this business. Two of the airports in the cluster are in close geographic proximity to each other (Cincinnati/Northern Kentucky and Indianapolis), as well as to two of the major US cargo airports (Memphis and Louisville), highlighting the geographic concentration of air cargo in the Indianapolis-Cincinnati-Memphis triangle. Some of these airports are in close proximity to large international gateways (e.g. Indianapolis is about 290km from Chicago O'Hare while Ontario is about 75 km from Los Angeles International), which helps the cargo airlines to achieve similar advantages as low-cost airlines generate in passenger markets (Boquet, 2008). Three of the US airports in this cluster are all secondary hubs or "*regional mini-hubs*" (Alkaabi and Debagge, 2011, p. 1521) for either FedEx or UPS (Bowen, 2012), while Cincinnati/Northern Kentucky is a hub for Polar Air Cargo (2015) and ABX Air (2015). Particularly the FedEx hub in Indianapolis is the second most important hub for the integrator after Memphis (Bowen, 2012). Winnipeg is secondary hub for Cargojet, a Canadian cargo airline (Cargojet, 2015a). Besides its own operations, Cargojet has been the main domestic air cargo provider to UPS in Canada since 2003 (Cargojet, 2015b).

In comparison to the North American Cargo Primaries, cargo volumes are significantly smaller and therefore these airports are less reliant on cargo alone, with passenger numbers also playing an important role. Airports in this cluster are "secondary" in two ways: they are of secondary importance in the hub-and-spoke network of cargo airlines and in some cases are secondary airports within a region (i.e. smaller airports within a similar catchment area to a larger airport).

4.6 Cluster 5: International Primary Hubs

Cluster 5 comprises of 17 major international airports, of which five are in the top ten airports by passenger numbers and seven in the top ten airports for total cargo tonnage. This highlights the importance of these airports both in passenger and cargo markets, with most of the airports in this cluster being hubs for major international network airlines (e.g. Emirates, Air France, American Airlines). Therefore this cluster is labelled "*International Primary Hubs*". From a geographic perspective, these airports can be found in the major economic centres around the globe, particularly in North America, Europe and Asia as well as the Middle East. Besides the "North American Cargo Primaries", this cluster has the second largest average cargo throughput p.a. with just under 2 million tonnes on average. At the same time, airports in this cluster have the highest average passenger numbers p.a. of all clusters. Therefore, while cargo in total numbers is significant, as a share of the total WLU, cargo only accounts for 27% on average at these airports. The share of freighter aircraft for this cluster is 6.65%. Despite the high volume of cargo, cargo at these airports is mainly produced as a "by-product" of their passenger operations. This means that even though the absolute volume of cargo at the airports, as a share of the business, this segment is of lesser importance than passengers.

4.7 Cluster 6: International Secondary Hubs

Cluster 6 is the largest and most diverse cluster from a geographic perspective, covering 42 airports in all regions, apart from North America. Many of the airports in this group are hubs for smaller network airlines (e.g. Swiss, South African Airways, AeroMéxico, Kenya Airways). While there is some cargo throughput at these airports in total numbers, as share of the WLUs, cargo is only responsible for 12.75% on average, with the majority being international cargo. This leads to this cluster being labelled "*International Secondary Hubs*". Freighter aircraft at these airports only account for about 4% of the commercial movements. Airports in this cluster generate on average 17.19m passenger p.a., with over 70% being international passengers. Airports in this cluster mainly rely on passenger operations and, similarly to the International Primary Hubs, generate cargo mainly as a by-product. Changes in the cargo market therefore have little impact on these airports.

4.8 Cluster 7: Passenger Dominant Airports (International)

This cluster consists of 15 airports with relatively high passenger numbers (average 27.68m p.a.), with some of the larger airports also processing high volumes of cargo. However, overall for these airports, cargo is of minor importance with on average only 8.2% of WLUs being cargo and 2.2% being freighter movements. Both on the passenger and cargo side, about half of the operations relate to international passengers and international cargo. Together with Cluster 8, these airports are the least reliant on cargo throughput, hence this cluster is labelled "*Passenger Dominant Airports (International)*".

4.9 Cluster 8: Passenger Dominant Airports (Domestic)

Cluster 8 is characterised by the lowest importance of air cargo, both in absolute and relative terms (total cargo throughput and share of WLUs), as well as when analysing freighter aircraft movements. The main difference to Cluster 7 lies in the domestic orientation of these airports in passenger and cargo markets with few international passengers and cargo tonnage recorded at these airports. This is partly related to the geographic location of these airports, which can be found mainly in large countries (predominantly the US and China). Based on their characteristics, this cluster is labelled: "*Passenger Dominant Airports (Domestic)*". Overall, airports in this cluster are mainly focussing on passenger operations and are not reliant on cargo as part of their business.

5 Discussion and Conclusions

The aim of this paper is to classify airports according to their air cargo characteristics and go beyond traditional labels of airports as "cargo airports". Previous research groups airports that see substantial amounts of cargo (often without quantifying this) together. However by purely looking at volumes, even when quantified, the relative importance of air cargo for each airport is neglected. By using a range of metrics, both absolute and fractional, this paper provides an insight into different airports from a cargo perspective.

Eight homogenous airports groups are identified. Airports in clusters 6, 7 and 8 show little reliance on air cargo operations and also only play a marginal role globally with low total cargo volumes. These airports are fairly immune to changes in the cargo environment, which results in little impact on airport operations and management. At times when the cargo environment is challenging, this means fewer negative impacts on these airports. However, as many cargo airlines are considering airports' attention to cargo when deciding where to locate their operations (Gardiner et al., 2005), these airports will find it more difficult to attract (new) cargo business.

The remaining five clusters, while all being more relevant to and reliant on cargo markets, also show a heterogeneous picture of air cargo at airports. As such, air cargo reliance and importance can be expressed as a spectrum with Cluster 1, “Cargo-dependent Europeans”, being the most reliant airport group on air cargo, with the majority of WLUs stemming from this business segment. Next, the cargo-dependent US airports not only differentiate themselves from their European counterparts by their geographic outlook (domestic vs international), the North American airports also record significantly larger volumes. Further in the spectrum are the European Dual-Bases and North American Cargo Secondaries that show a more equal split between the cargo and passenger business. Finally, the International Primary Hubs, while registering large volumes of cargo, show a significantly lower share of cargo WLUs, as a result of high passenger throughput at these airports.

Not only are the clusters externally diverse when analysing their cargo characteristics, but they are also internally homogenous from a geographic perspective, with airports showing similar characteristics having a similar geographic location or centrality within a network. Airports that are highly dependent on cargo, namely in clusters 1, 2, 3 and 4, benefit from their central location in Europe and North America respectively. This is also linked to the hub-and-spoke structure of integrators and air express companies that have their hubs at these airports. While the European airports mainly cater for an international market (bearing in mind that intra-EU traffic is recorded as international), the US airports predominantly serve the domestic market. In total volume, the International Primary Hubs are not only major players in passenger markets but also in the cargo business. As such, for these airports centrality within a region is of lower importance, but these airports benefit from high cargo volumes generated by passenger aircraft. Therefore the management of cargo at these airports requires a different approach to the more cargo-dependent airports in clusters 1, 2, 3 and 4.

This paper helps to identify comparator airports when developing benchmarking exercises in the air cargo market. For example, when purely looking at the total volumes of cargo at an airport, Hong Kong and Memphis are the two largest airports. However these two airports have a very different cargo profile, different centrality within cargo networks and different types of airlines operating passenger and cargo flights from the airport. Therefore comparing these two airports in a benchmarking exercise would produce few benefits and has little practical relevance. As such, regional differences need to be understood, which is shown by the geographic similarities of the different airports from a cargo perspective. Furthermore, the air cargo market is currently very challenging for airlines and airports, with limited growth since 2010. Therefore, this paper helps to identify those airports that are most vulnerable to changes in the cargo market, both from a domestic as well as international perspective. This will become more relevant in future, with the share of freighter aircraft predicted to decline (CAPA, 2014) and therefore leaving airports that more reliant on freighter operations more exposed to these changes.

Cargo has hardly featured in airport research, particularly when looking at airport classification. A major hurdle that needs to be overcome in this respect is data availability. While operational data, as used in this paper, is available to some extent, information on financial aspects (e.g. cargo revenues and costs) is hardly available and is usually aggregated with other business activities which makes further analysis on financial aspects of air cargo at airports challenging. Further research could also focus on operational aspects. These were excluded in this paper as operational aspects are more difficult to quantify in many cases. For example, while there is a night curfew in place at Leizpig/Halle airport, this does not affect airlines that operate a cargo terminal at the airport (Boeing, n.d.). Future research could focus on an operational analysis of different cargo airports.

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References

ABX Air (2015). About Us [online]. Available at: https://www.abxair.com/about/index.cfm (Accessed 22 September 2015).

ACI (2010). *An Outlook for Europe’s Airports*. Airports Council International, Brussels.

ACI (2012). *Guide to Airport Performance Measures*. Airports Council International, Montreal.

ACI (2014). *2013 ACI annual world airport traffic report*. Airports Council International, Montreal.

Adikariwattage, V., de Barros, A. G., Wirasinghe, S. C. and Ruwanpura, J. (2012). Airport classification criteria based on passenger characteristics and terminal size. *Journal of Air Transport Management*, 24, pp. 36-41.

Adler, N. and Liebert, V. (2014). Joint impact of competition, ownership form and economic regulation on airport performance and pricing. *Transportation Research Part A*, 64, pp. 92-109.

Alkaabi, K. A. and Debbage, K. G. (2011). The geography of air freight: connections to U.S. metropolitan economies. *Journal of Transport Geography*, 19, pp. 1517-1529.

Anable, J. (2005). „Complacent Car Addicts“ or „Aspiring Environmentalists“? Identifying travel behaviour segments using attitude theory. *Transport Policy*, 12, pp. 65-78.

A. T. Kearney (2010). China 2015: Transportation and Logistics Strategies [online]. Available at: https://www.atkearney.com/documents/10192/74d60d15-dc42-48a3-8dc8-7a2297f0be22 (Accessed 22 April 2016)

Boeing (n.d.). Airports with Noise and Emissions [online]. Available at:Restrictionhttp://www.boeing.com/resources/boeingdotcom/commercial/noise/lepizig.html#cur (Accessed 22 April 2016).

Boquet, Y. (2009). Les hubs de fret aérien express. *Bulletin de l'Association de Géographes francais*, 86/4, pp. 472-484.

Bowen, J. T. (2012). A spatial analysis of FedEx and UPS: hubs, spokes, and network structure. *Journal of Transport Geography*, 24, pp. 419-431.

Branson, R. *Foreword* in, Sale, M. (2013). *The Air Logistics Handbook*. Routledge, Abingdon.

Burns, R. P. and Burns, R. (2008). *Research Methods and Statistics using SPSS*. Sage Publications, London.

Button, K. and Yuan, J. (2013). Airfreight Transport and Economic Development: An Examination of Causality. *Urban Studies*, 50/2, pp. 329-340.

CAPA (2013a). Chinese air cargo shifts from Shanghai to the Three Cs: Chengdu, Chongqing and CGO [online]. Available at: http://centreforaviation.com/analysis/chinese-air-cargo-shifts-from-shanghai-to-the-three-cs-chengdu-chongqing-and-cgo-97465 (accessed 22 April 2016).

CAPA (2013b). As trans-Pacific passenger flights increase, hold capacity drives structural changes in air cargo [online]. Available at: http://centreforaviation.com/analysis/as-trans-pacific-passenger-flights-increase-hold-capacity-causes-structural-changes-to-air-cargo-124411 (accessed 22 September 2015).

CAPA (2014). Asian air cargo overview: different profiles for major freight airlines, but united in weak outlook [online]. Available at: http://centreforaviation.com/analysis/asian-air-cargo-overview-different-profiles-for-major-freight-airlines-but-united-in-weak-outlook-173842 (accessed 22 September 2015).
Cargojet (2015a). Freighter Schedule [online]. Available at: http://www.cargojet.com/assets/FILES/CARGOJET_SCHD.pdf (Accessed 22 September 2015).
Cargojet (2015b). Cargojet & UPS Enter Into Long-Term Air Cargo Services Agreement [online]. Available at: http://www.cargojet.com/pressReleases/2015/2015-18.htm (Accessed 22 September 2015).
Cincinnati/Northern Kentucky International Airport (2014). Special Purpose Financial Statements December 31, 2014 and 2013. Available at: https://www.cvgairport.com/docs/default-source/stats/cvg-2013-financials.pdf?sfvrsn=8 (Accessed 22 September 2015)
Dart Group (2015). Jet2.com [online]. Available at: http://www.dartgroup.co.uk/jet2/ (Accessed 22 September 2015).
Davison, L. and Ryley, T. (2010). Tourism destination preferences of low-cost airline users in the East Midlands. *Journal of Transport Geography*, 18, pp. 458-465.
DHL (2008). DHL Hub Leipzig/Halle: The logistics hub that moves the world [online]. Available at: https://www.dpdhl.com/content/dam/logistik_populaer/leipzig_hub/hub-leipzig_en.pdf (Accessed 22 September 2015).
East Midlands Airport (2015). About us and our group [online]. Available at: http://www.eastmidlandsairport.com/emaweb.nsf/Content/AboutOurGroup (Accessed 22 September 2015).
Eurostat (2014). http://ec.europa.eu/eurostat/data/database. (Accessed 22 September 2015).
FedEx (2014). Annual Report 2013 [online]. Available at: http://www.sec.gov/Archives/edgar/data/1048911/000119312514267851/d752614d10k.htm (Accessed 22 September 2015)
Flightglobal (2015). pro.flightglobal.com database. (Accessed 22 September 2015).
Gardiner, J. and Ison, S. (2008). The geography of non-integrated cargo airlines: an international study. *Journal of Transport Geography*, 16, pp. 55-62.
Gardiner, J., Ison, S. and Humphreys, I. (2005). Factors influencing cargo airlines' choice of airport: An international survey. *Journal of air Transport Management*, 11/6, pp. 393-399.
Germanwings (2015). Facts and Figures [online]. Available at: https://www.germanwings.com/content/dam/germanwings/downloads/EN/germanwings-facts-and-figures_en.pdf (Accessed 22 September 2015).
Graham, A. (2005). Airport benchmarking: a review of the current situation. *Benchmarking: An International Journal*, 12/2, pp. 99-111.
Hair, J. F., Anderson, R. E., Tatham, R. L. and Black, W. C. (1998). *Multivariate Data Analysis*. 5th ed., Prentice Hall, Upper Saddle River.
Hesse, M. (2014). International hubs as factor of local development: evidence from Luxembourg City, Luxembourg, and Leipzig, Germany. *Urban Research & Practice*, 7/3, p. 337-353.
Hesse, M. and Rodrigue, J.-P. (2004). The transport geography of logistics and freight distribution. *Journal of Transport Geography*, 12, pp. 171-184.
IATA (2013). Profitability and the air transport value chain. *IATA Economics Briefing No 10*.
IATA (2014a). Economic performance of the airline industry: 2014 mid-year report [online]. Available at: https://www.iata.org/whatwedo/Documents/economics/IATA-Economic-Performance-of-the-Industry-mid-year-2014-report.pdf (accessed 22 September 2015).
IATA (2014b). Air Cargo [online]. Available at: http://www.iata.org/whatwedo/cargo/pages/index.aspx (accessed 22 September 2015).
IATA (2014c). IATA World Air Transport Statistics 2014. International Air Transport Association, Montreal/Geneva, 58th edition.

IATA (2015). Cargo Chartbook 2015 Q3 [online]. Available at: http://www.iata.org/whatwedo/Documents/economics/cargo-chartbook-Q3-2015.pdf (accessed 22 September 2015).
ICAO Data+ (2014). ICAO Data+ database. https://stats.icao.int/ (accessed 15 December 2014).
Jarach, D. (2001). The evolution of airport management practices: towards a multi-point, multi-service, marketing-driven firm. *Journal of Air Transport Management*, 7, pp. 119-125.
Kalakou, S. and Macário, R. (2013). An innovative framework for the study and structure of airport business models. *Case Studies on Transport Policy*, 1, pp. 2-17.
Kasarda, J. D. and Green, J. D. (2005). *Air cargo as an economic development engine: A note on opportunities and constraints*. *Journal of Air Transport Management*, 11/6, pp. 459-462.
Luxair (2014). LuxairGroup Annual report 2014 [online]. Available at: http://www.luxairgroup.lu/cms/luxair.php?p=,,,,,7bcad0b65321237a32d07c3a6268b506 (Accessed 22 September 2015).
Malighetti, P., Paleari, S. and Redondi, R. (2009). Airport classification and functionality within the European network. *Problems and Perspectives in Management*, 7/1, pp.183-196.
Martinez-Garcia, E. and Royo-Vela, M. (2010). Segmentation of low-cost flights users at secondary airports. *Journal of Air Transport Management*, 16/4, pp. 234-237.
Morrell, P. S. (2011). *Moving Boxes by Air*. Ashgate, Farnham.
Neiberger, C. (2008). The effects of deregulation, changed customer requirements and new technology on the organisation and spatial patterns of the air freight sector in Europe. *Journal of Transport Geography*, 16, pp. 247-256.
Norušis, M. J. (2011). *IBM SPSS Statistics 19 Statistical Procedures Companion*. Pearson, London.
Oum, T. H. and Yu, C. (2004). Measuring airports' operating efficiency: a summary of the 2003 ATRS global airport benchmarking report. *Transportation Research Part E*, 40, pp. 515-532.
Pearce, B. (2012). The state of air transport markets and the airline industry after the great recession. *Journal of Air Transport Management*, 21, pp. 3-9.
Polar Air Cargo (2015). Network Map [online]. Available at: http://www.polaraircargo.com/networkmap.html (Accessed 22 September 2015).
Punj, G. and Stewart, D. W. (1983) Cluster Analysis in Marketing Research: Review and Suggestions for Application. *Journal of Marketing Research*, XX, pp. 134-148.
Rodríguez-Déniz, H., Suau-Sanchez, P. and Voltes-Dorta, A. (2013). Classifying airports according to their hub dimensions: an application to the US domestic network. *Journal of Transport Geography*, 33, pp. 188-195.
Ryanair (2014). Annual Report 2014 [online]. Available at: http://investor.ryanair.com/wp-content/uploads/2015/04/2014-Annual-Reports-Annual-Report.pdf (Accessed 22 September 2015).
Sale, M. (2013). *The Air Logistics Handbook*. Routledge, Abingdon.
Sarkis, J. and Talluri, S. (2004). Performance based clustering for benchmarking of US airports. *Transportation Research Part A*, 38/5, pp. 329-346.
Seabury (2014). Modal shift costing air freight 2 percentage points of annual growth, Seabury-IATA report finds [online]. Available at: http://www.seaburygroup.com/news/210-modal-shift-costing-air-freight-2-percentage-points-of-annual-growth-seabury-iata-report-finds (accessed 22 September 2015).
TNT (2011). TNT Euro Hub at a glance [online]. Available at: http://www.tntliege.com/48_TNT+Euro+Hub+at+a+glance.html (Accessed 22 September 2015).
UPS (2014). Annual Report 2013 [online]. Available at: http://www.sec.gov/Archives/edgar/data/1090727/000109072714000009/ups-12312013x10k.htm (Accessed 22 September 2015).

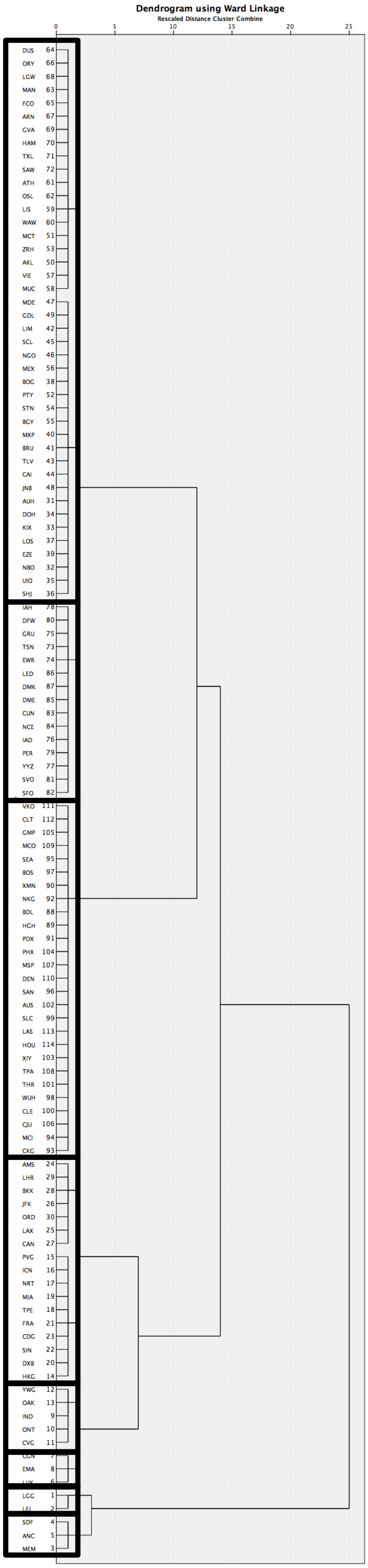
Vogel, H.-A. and Graham, A. (2013). Devising airport groupings for financial benchmarking. *Journal of Air Transport Management*, 30, pp. 32-38.
Wang J. J. and Cheng, M. C. (2010). From a hub port city to a global supply chain management centre: a case study of Hong Kong. *Journal of Transport Geography*, 18, pp. 104-115.
Yuan, X.-M., Low, J. M. W. and Tang , C. T. (2010). Roles of the airport and logistics services on the economic outcomes of an air cargo supply chain. *International Journal of Production Economics*, 127, pp. 215-225.
Zhang, A. (2003). Analysis of an international air-cargo hub: the case of Hong Kong. *Journal of Air Transport Management*, 9, pp. 123-138.

Appendix A

IATA Code	Airport Name	Region
AKL	Auckland International Airport	ASP
AMS	Amsterdam Airport	EUR
ANC	Ted Stevens Anchorage International Airport	NAM
ARN	Stockholm-Arlanda Airport	EUR
ATH	Athens International Airport	EUR
AUH	Abu Dhabi International Airport	MEA
AUS	Austin-Bergstrom International Airport	NAM
BDL	Bradley International Airport (Hartford)	NAM
BGY	Orio al Serio International Airport (Bergamo)	EUR
BKK	Suvarnabhumi International Airport (Bangkok)	ASP
BOG	Aeropuerto Internacional El Dorado (Bogota)	LAC
BOS	Logan International Airport (Boston)	NAM
BRU	Brussels National Airport	EUR
CAI	Cairo International Airport	AFR
CAN	Guangzhou Bai Yun International Airport	ASP
CDG	Aéroport de Paris-Charles de Gaulle	EUR
CGN	Köln-Bonn Airport	EUR
CJU	Jeju International Airport	ASP
CKG	Chongqing Jiangbei International Airport	ASP
CLE	Cleveland Hopkins International Airport	NAM
CLT	Charlotte Douglas International Airport	NAM
CUN	Cancún International Airport	LAC
CVG	Cincinnati/Northern Kentucky International Airport	NAM
DEN	Denver International Airport	NAM
DFW	Dallas/Ft Worth International Airport	NAM
DME	Domodedovo International Airport (Moscow)	EUR
DMK	Don Mueang International Airport (Bangkok)	ASP
DOH	Doha International Airport	MEA
DUS	Düsseldorf International Airport	EUR
DXB	Dubai International Airport	MEA
EMA	East Midlands Airport	EUR
EWR	Newark Liberty International Airport	NAM
EZE	Aeropuerto Internacional de Ezeiza (Buenos Aires)	LAC
FCO	Aeroporto di Roma-Fiumicino	EUR
FRA	Flughafen Frankfurt/Main	EUR
GDL	Aeropuerto Internacional de Guadalajara	LAC
GMP	Gimpo International Airport (Seoul)	ASP
GRU	Guarulhos International Airport (São Paulo)	LAC
GVA	Aéroport International de Genève	EUR
HAM	Flughafen Hamburg	EUR
HGH	Hangzhou Xiaoshan International Airport	ASP
HKG	Hong Kong International Airport	ASP
HOU	W. P. Hobby Airport (Houston)	NAM
IAD	Washington Dulles International Airport	NAM
IAH	George Bush Intercontinental Airport (Houston)	NAM
ICN	Incheon International Airport (Seoul)	ASP
IND	Indianapolis International Airport	NAM
JFK	John F. Kennedy International Airport (New York)	NAM
JNB	OR Tambo International Airport (Johannesburg)	AFR
KIX	Kansai International Airport (Osaka)	ASP
LAS	McCarran International Airport (Las Vegas)	NAM
LAX	Los Angeles International Airport	NAM
LED	Pulkovo Airport (St Petersburg)	EUR
LEJ	Flughafen Leipzig/Halle	EUR
LGG	Liège Airport	EUR
LGW	Gatwick Airport (London)	EUR
LHR	Heathrow Airport (London)	EUR
LIM	Aeropuerto Internacional “Jorge Chávez” (Lima)	LAC
LIS	Lisbon Airport	EUR
LOS	Murtala Muhammed International Airport (Lagos)	AFR
LUX	Luxembourg-Findel International Airport	EUR
MAN	Manchester Airport	EUR
MCI	Kansas City International Airport	NAM

MCO	Orlando International Airport	NAM
MCT	Muscat International Airport	MEA
MDE	Jose Maria Cordoba International Airport (Medellin)	LAC
MEM	Memphis International Airport	NAM
MEX	Aeropuerto Internacional de la Ciudad de México "Lic Benito Juárez"	LAC
MIA	Miami International Airport	NAM
MSP	Minneapolis/St Paul International Airport	NAM
MUC	Munich Airport	EUR
MXP	Milano Malpensa	EUR
NBO	Jomo Kenyatta International Airport (Nairobi)	AFR
NCE	Aeroport Nice Cote d'Azur	EUR
NGO	Central Japan International Airport (Nagoya)	ASP
NKG	Nanjing Lukou International Airport	ASP
NRT	Narita International Airport (Tokyo)	ASP
OAK	Oakland International Airport	NAM
ONT	LA/Ontario International Airport	NAM
ORD	O'Hare International Airport (Chicago)	NAM
ORY	Aéroport de Paris-Orly	EUR
OSL	Oslo Airport	EUR
PDX	Portland International Airport	NAM
PER	Perth Airport	ASP
PHX	Sky Harbor International Airport (Phoenix)	NAM
PTY	Aeropuerto Internacional de Tocumen (Panama City)	LAC
PVG	Pudong International Airport (Shanghai)	ASP
SAN	San Diego International Airport	NAM
SAW	Sabiha Gökçen International Airport (Istanbul)	EUR
SCL	Aeropuerto Internacional Arturo Merino Benitez (Santiago)	LAC
SDF	Louisville International Airport	NAM
SEA	Seattle-Tacoma International Airport	NAM
SFO	San Francisco International Airport	NAM
SHJ	Sharjah International Airport	MEA
SIN	Singapore Changi Airport	ASP
SLC	Salt Lake City International Airport	NAM
STN	Stansted Airport (London)	EUR
SVO	Sheremetyevo International Airport (Moscow)	EUR
THR	Mehrabad International Airport (Tehran)	MEA
TLV	Ben Gurion International Airport (Tel-Aviv)	MEA
TPA	Tampa International Airport	NAM
TPE	Taiwan Taoyuan International Airport	ASP
TSN	Tianjin Binhai International Airport	ASP
TXL	Tegel Airport (Berlin)	EUR
UIO	Mariscal Sucre International Airport (Quito)	LAC
VIE	Vienna International Airport	EUR
VKO	Vnukovo International Airport (Moscow)	EUR
WAW	Warsaw Frederic Chopin Airport	EUR
WUH	Wuhan Tianhe Airport	ASP
XIY	Xi'an-Xianyang International Airport	ASP
XMN	Xiamen Gaoqi International Airport	ASP
YWG	Winnipeg James Armstrong Richardson International Airport	NAM
YYZ	Toronto Pearson International Airport	NAM
ZRH	Flughafen Zürich	EUR

Appendix B



Dendrogram using Ward Linkage
Rescaled Distance Cluster Combine

Airport classification based on cargo characteristics

Mayer, Robert

2016-05-28

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