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The evolution of airports from a network perspective – An analytical concept

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Abstract Analyzing airports' role in global air transportation and monitoring their development over time provides an additional perspective on the dynamics of network evolution. In order to understand the different roles airports can play in the network an integrated and multi-dimensional approach is needed. Therefore, an approach to airport classification through hierarchical clustering considering several parameters from network theory is presented in this paper. By applying a 29 year record of global flight data and calculating the conditional transition probabilities the results are displayed as an evolution graph similar to a discrete-time Markov chain. With this analytical concept the meaning of airports is analyzed from a network perspective and a new airport taxonomy is established. The presented methodology allows tracking the development of airports from certain categories into others over time. Results show that airports of equal classes run through similar stages of development with a limited number of alternatives, indicating clear evolutionary patterns. Apart from giving an overview of the results the paper illustrates the exact data-driven approach and suggests an evaluation scheme. The methodology can help the public and industry sector to make informed strategy decisions when it comes to air transportation infrastructure.

1. Introduction

As early as 1945 Caroline and Walter Isard foresaw that air transportation will have a vital effect on the global market structure leading to a new spatial division.[1] This statement has never been more applicable than today, since mobility is a characteristic of the new global world order[2] where a new division of labor[3] emerged and high-cost, low-bulk freight including perishable commodities is being distributed globally irrespective of its production site. This crucial impact of air transportation on economic activity is commonly considered to occur on two levels.[4] (1) The 'enabling or catalytic impact' incorporates economic activity that relies on the 'availability of air transportation services'. (2) The 'direct, indirect and induced employment impact' refers to 'the employment in the aviation industry', the employment along the according supply chain and the employment generated 'by the spending

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of those directly and indirectly employed'. One can deduce the significance of the two aforementioned levels of economic impact for the development of a city and region. While an important metropolis is rather dependent on the catalytic impact of air transportation, a city with a major hub-airport particularly benefits from direct, indirect and induced employment. But it also provides accessibility to its hinterland which again is dependent on the catalytic impact. Furthermore, over time cities with hub-airports benefit from their central position in the air transportation network and the strategic decisions made by airlines. New companies that are in search of premises with good global accessibility are likely to locate in the vicinity. These economic mechanisms make clear why public authorities have always focused on infrastructure investments as a means of regional development. But the air transportation network has undergone a great deal of change in the past decades, which can be traced to the growing national economies and major investments in the Far and the Middle East, to innovative aircraft technologies, to market deregulation and to the rise of low cost carries. The network transition made it difficult for public authorities and airport executives to make the right strategic decision for their airport. And according to the Boston Consulting Group[5] the first step is to soberly assess the airports' role in the new network to determine possible investments and carrier strategies.

The objective of this paper is to contribute to the assessment of airports and their changing role within the global air transportation network. The paper presents a new approach to classifying airports from a worldwide network perspective and monitoring their development over time to reveal evolutionary patterns. There are some studies that analyze the meaning of airports to the global air transportation system. Many of these use a theoretical traffic model to analyze traffic flows and the airports' relevance to the system.[6–8] Others try to identify structures within the real data traffic flow[9] or apply measures from network theory.[10] However, none of these studies actually describe airports and their meaning to the overall system from a complex network perspective. The different approaches presented in these studies also do not cope well with a large set of airports or longitudinal data.

The issues of airport classification and airport evolution from a network perspective have been addressed in very few scientific studies. The closest reference to this paper can probably be found in Malighetti et al.[11] and Burghouwt and Hakfoort[12] but there are other studies with a similar focus.[13,14] However, these studies mainly focus on the hub-qualities of airports in certain world areas and lack the global view. In addition, these studies do not aim to analyze the airports' changing role over time but try to determine a current state. While the approach presented in these studies helps to analyze a large set of airports in their relation to the overall network they do not present a method to analyze airport development. The substantially new methodological approach presented in this paper allows classifying airports and revealing their changing role in the network over time. It also finds general patterns of airport evolution and reasons them with their geographical context. Last but not least, this study is unique in its temporal and geographical scope, due to the exceptional 29 year global flight data record. The presented approach combines network theory, cluster analysis and probability theory in the form of an evolution graph inspired by the Markov chain. The results are validated by adapting a known evaluation model and presented by a new visualization scheme for better interpretation. This comprehensive data mining approach was developed specifically for this research study to cope with the extremely large data set that was available for analysis. The methodology is specified in the following.

2. General approach

Clustering is the methodological basis for the analytical concept presented here. Cluster analysis as a computer-based pattern recognition tool allows revealing structures and regularities within data.[15] In contrast to supervised classification where the classes are known beforehand, unsupervised classification or clustering is a data driven approach that groups all tuples with similar features.[16] The algorithms are designed in a way that the objects within one identified group have maximum similarity among each other and minimum similarity to objects of other groups.[17] The analytical concept presented here allows identifying meaningful airport classes based on various parameters from network theory. The applied data set is the Official Airline Guide (OAG) flight schedules database from 1979 to 2007. The cluster analysis is not performed repeatedly on a yearly basis, but instead the airport data for the entire time period is clustered at once and the tuples merely keep their time stamp for subsequent analyses. This means, that the applied data set consists of a large number of tuples, where each tuple represents different network parameters for a single airport at a certain time. This approach has the crucial advantage, that new classes of airports that have evolved later in time can be identified as such.

In the second part of the analytical concept the assumption is made that the process of airport development is quasi-stationary and therefore can be represented by an evolution graph inspired by a first order Markov chain. Fig. 1 illustrates the evolution graph in which vertices represent airport classes and edges represent transition probabilities. In addition, the vertices are visualized as radar charts to indicate the parametric properties of each airport category. This helps identifying which role airports of a certain class play in the global network. From the historical data and cluster analysis the frequencies in which airports developed from one class into another are calculated to determine the conditional transition probabilities between all pairs of classes. The transition probabilities of the evolution graph (Fig. 1) in the context of this work are the conditional probabilities, with which an airport X of a certain class C_i at time T_1, previously belonged to a certain other class C_j at the previous time step T_0. Therefore, it holds that $P(X_{T_0} \in C_j | X_{T_1} \in C_i)$ for the weights of the edges in the evolution graph. Put simply, the airports of one class

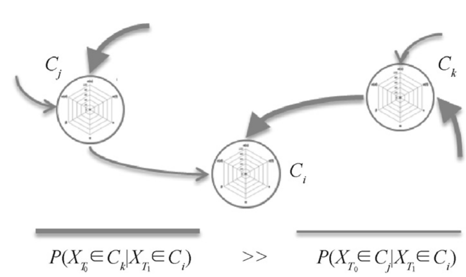

Fig. 1 Evolution graph.