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An exploratory analysis on the evolution of the US airport network

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HIGHLIGHTS

- We examine the evolution of the US airport network (USAN) from 1990 to 2010.
- The USAN has experienced drastic changes in both its structure and traffic in 2002.
- The USAN preserves the scale-free, small-world, and disassortative mixing properties over time.
- Stable cities in the USAN form the backbone and show structural regularity over time.
- New cities in the USAN indicate an evolution of continuous densification and intense exploration.

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ABSTRACT

Airport network has a nontrivial impact on shaping the development of a country or region, and decision makers or researchers can benefit from its evolution characteristics. This paper presents an exploratory analysis on the evolution of the US airport network from 1990 to 2010. Generally, we find that (1) the USAN has experienced a drastic change in both its structure and traffic amount in the year 2002. Particularly, regarding the entire USAN, we show that (2) it preserves the scale-free, small-world, and disassortative mixing properties over time which is consistent with the previous studies. Thereafter, the evolution of the USAN is examined from two perspectives: stable cities that never disappear in the time period and new cities that only appear in certain years. Findings from the first perspective imply that (3) stable cities form the backbone of the USAN over time and their structural similarity over time shows regularity. On the other hand, results from the second one indicate that (4) the USAN is undergoing a process of continuous densification intertwined with intense exploration in 1991 and 2002, which consequently leads to a stable USAN.

1. Introduction

The past few years have witnessed the availability of huge data [1], which allow researchers from many disciplines to analyze and model a diverse range of networked structures. Typical examples include the information network like the World Wide Web [2], technical network like power grid network [3], biological network like brain neural network [4], social network like scientific collaboration network [5], and even the transportation network e.g., railway network or airport network [6]. A network is composed of nodes and links and hides the principles or mechanisms of the underlying phenomena in a large extent. Due to the development of network theory, we can employ the tools or methods in complex network theory

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to understand its structure and function. Taking the transportation network as an example, it is composed of stations and routes, from which one may understand how the transportation organizes and the traffic flows.

Transportation network tends to act as a useful indicator to imply the socioeconomic development level of a country or region. Extensive attentions have been paid to investigate its structural and traffic properties as well as the evolution regularities with respect to different transportation modes. The global maritime transportation network was revealed to have the small-world property, hierarchical structure, and the rich-club phenomenon [7]. The evolution of urban road network in Italy has been recently examined in Ref. [8], and their findings suggest that urban road network evolves with a mutual process of exploration and densification. Moreover, the evolution of railway transportation network in China has been evaluated in terms of its spatial accessibility, relation to economic growth, and the formation of urban systems [9]. Similarly, the public transportation network in Singapore has been investigated in Ref. [10]. Their investigation of travel routes with both railways and buses endorses the importance of dynamical and temporal analysis, apart from the traditional topological analysis.

Compared with the aforementioned transportation modes, airport transportation network is expanding at a fast pace in recent years, and it occupies a large proportion of domestic and intercontinental traffic due to advantages of time-saving and economical cost. Although the flight prices are high in some regions, the short travel time may overwhelm this disadvantage and instead become the major motivation for traveling by air [11]. In the US, the deregulation of airline industry has resulted in a wide spread studies from both academic community and policy making agencies [12]. These studies show that the general public in the US have benefited a lot from this deregulation policy, and particularly it leads to the formation of hub-and-spoke structure [13], which in turn motivates more people to use air transportation as their travel mode. Moreover, airport network has nontrivial impact on the economy of a country or region such that understanding its evolution characteristics can benefit decision makers in different fields and researchers in network modeling and prediction.

Hence, research on airport network and its evolution has become a hot topic that attracts a wide range of attentions. The evolution of Chinese airport network has been investigated in Ref. [14] from the year 1950 to 2008, and they reported the stability of topological structure over years and the exponential growth of traffic with evident seasonal fluctuations. The evolution of Brazilian airport network has been examined in Ref. [11] for a period of 11 years from 1995 to 2006, and the findings indicate that the structure is dynamic with changes in relevance to airports and the traffic grows almost double times along with the shrinkage of network at route level. Ref. [15] studied the evolution of the US airport network in the period of 1990–2000 and found that most network metrics are stable with a small fluctuation and the dynamics of connections with appearing/disappearing between airports occur intensively at the local level. As for the evolution of European airport network from 1990 to 1998, Ref. [13] showed that intra-European traffic does not concentrate on a small number of hubs while inter-continental traffic does at the airport level and that hub-and-spoke structure is observed at the route level.

Inspired from the above findings, this paper explores the evolution of the US airport network (USAN) in the time period 1990–2010, and presents several findings that were not observed in the previous studies. In this paper, the USAN is modeled as a weighted network with cities as nodes and airlines between cities as links. Particularly, the evolution of the USAN is examined from three aspects: the entire USAN, stable cities and their traffic, new cities and their traffic. Stable cities refer to the ones occurring during the study period and new cities denote the ones being newly occurred in the current year not found in the previous year. The first view allows us to understand how traffic dynamics and topological structure as a whole change over time, while the second view sheds clear insight on the evolution of stable cities, which form the backbone of the entire USAN and helps on comprehending how individual stable cities evolve using similarity measurement. The last view gives us the opportunity to look at the evolution of new cities and their traffic, which opens a vista to depict the evolution mechanism of the USAN.

The remainder of this article is structured as follows. In Section 2, we describe the dataset adopted and the corresponding methodologies. The evolution of the entire USAN is investigated in Section 3. In Section 4, we report the findings on the evolution of the USAN from the perspective of stable cities. In Section 5, we elaborate the results on the evolution of the USAN from the perspective of new cities. In Section 6, issues regarding the evolving network or particularly the USAN are discussed. Finally, conclusions are drawn in Section 7.

2. Dataset and measurements

2.1. Dataset

This paper adopts the dataset provided by the Bureau of Transportation Statistics which can be downloaded via its official website (http://www.transtats.bts.gov/). The transportation data is organized into individual tables according to year, and hence we manually downloaded 21 tables from year 1990 to 2010. Each row in a table records the aggregated information of one airline operated from one original city to another destination city in one month, while the number of rows in each table gradually increases from around 150,000 in 1990 to 260,000 in 2010 (cf. Table 1). Each table includes 36 fields which cover much detailed information of the airline, such as passengers, freight, mail, distance, airline ID, original city, destination city, month, and so on. Besides, the total size of our dataset reaches about 750 MB.

The raw dataset is subsequently processed to build the US airport network for each year. Three steps are involved in this process, namely record validation, city geo-coding, and network construction. The first step aims to remove the invalid