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The devil is in the details: Differences in air traffic networks by scale, species, and season

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ABSTRACT

Although air traffic networks are widely studied examples of complex networks, past research has focused on only one type: the network of routes flown between airports. Although this network is important, other varieties of air traffic networks exist. This paper differentiates air traffic networks on dimensions of scale (airport vs. metropolitan area), species (business vs. leisure), and season (summer vs. winter). Although these networks share similar complex network topologies – they are scale-free, small-world, and modular – they are nonetheless different in substantively important ways. They capture different kinds of social and economic processes, are useful for investigating different kinds of research questions, and lead to different kinds of conclusions about how and where interactions are organized.

1. Introduction

Air traffic networks are widely studied as a form of complex network, and have been examined at the global (Barrat et al., 2004; Guimera and Amaral, 2004; Guimera et al., 2005), continental (Han et al., 2009), and national (Barabasi and Bonabeau, 2003; Xu and Harriss, 2008; Li and Cai, 2004; Bagler, 2008) scales. In each case, the air traffic network is cited as a prime example of a small-world, scale-free, modular network. However, these studies have examined only one specific type of air traffic network: the airport route network. Although this type of network is very important, representing the infrastructural backbone of long-distance travel, air traffic networks can be conceptualized in other ways that are socially and economically significant.

This purpose of this paper is twofold. First, it conceptually distinguishes and briefly reviews the existing literature on several types of air traffic networks along dimensions of scale (airport vs. metropolitan area), species (business passengers vs. leisure passengers), and season (summer vs. winter). Second, it compares these networks to explore their similarities and differences (c.f. Choi et al., 2006; Tranos, 2011). The comparison first focuses on three commonly discussed topological features of complex networks: small-world structure, scale-free degree distribution, and modular community structure. I then take a closer look at specific pairs of networks to uncover substantive differences that might be obscured by examining their topology alone. Given the recent focus by some to demonstrate the universality of complex network phenomena (e.g. Albert and Barabasi, 2002; Newman, 2003), and the focus by others to demonstrate the importance of networks' substantive contexts to understand their structures (Borgatti et al., 2009), of particular interest is whether the complex network architecture widely observed in airport routing networks extends to other forms of air traffic networks. Is it sufficient, for example, to observe that air traffic networks exhibit scale-free, small-world structures and thus to conclude that 'an air traffic network is an air traffic network,' or do complex network phenomena mask important substantive details unique to different types of air traffic networks? I conclude that despite topological similarities, different kinds of air traffic networks have unique structures, and thus that when using air traffic networks to understand social and economic processes, the devil is in the details.

2. Nested types of air traffic networks

Fig. 1 highlights the nested relationship among the seven types of air traffic networks examined below. The most widely studied type of air traffic network is the airport route network. In an airport route network, the nodes are individual airports and the edges reflect the number of passengers that took off from airport i and landed at airport j. It is perhaps the most familiar image of an airline network, mirroring the maps found at the back of inflight magazines. Because the data required to construct an airport route network is routinely collected by government agencies

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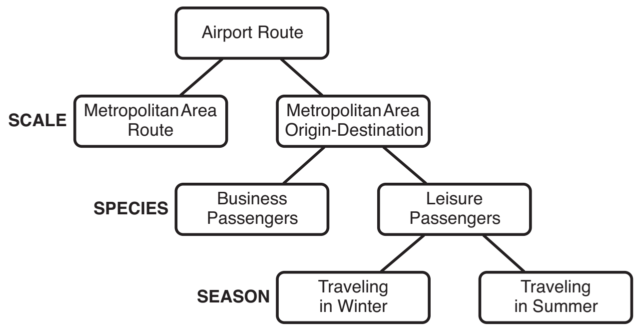

Fig. 1. Nested types of air traffic networks.

(e.g. US Federal Aviation Administration) and regulatory bodies (e.g. International Air Transport Association), and is readily available at both national and global scales, this type of network has been a favorite for those interested in understanding the topological properties of real-world networks (Barabasi and Bonabeau, 2003; Barrat et al., 2004; Guimera and Amaral, 2004; Li and Cai, 2004; Guimera et al., 2005; Bagler, 2008; Xu and Harriss, 2008; Han et al., 2009). However, airport route networks have also been used to capture and understand substantive (i.e. as opposed to abstract topological) phenomena. For example, because it describes the takeoff-and-landing patterns of aircraft, it is ideal for describing the operational structure of airline industries, including characterizing the transition of the US airline industry from a point-to-point route structure before deregulation, to a hub-and-spoke structure after 1978, and the subsequent re-emergence of point-to-point route structures among a few low-cost carriers like Southwest (Goetz and Sutton, 1997; O'Kelly, 1998; Reynolds-Feighan, 1998; Bowen, 2002). Similarly, it is often used by economists and transportation planners to evaluate the efficiency of hub location and to optimize routing patterns (Huston and Butler, 1991; Aykin, 1995; Button and Lall, 1999; Campbell and O'Kelly, 2012).

2.1. Scale: route vs. origin-destination

In research about the airline industry's operational structure or issues of logistic efficiency, it is important to distinguish between, for example, Chicago's O'Hare airport, which is a hub for American and United, and Chicago's Midway airport, which is a hub for Southwest. However, for questions about the movements of *people* rather than *aircraft*, it is often more useful to aggregate individual airports into metropolitan areas. Indeed, for a person wishing to travel from Chicago to Los Angeles, the decision whether to depart from O'Hare or Midway (and to arrive at LAX or Orange County) is driven by considerations of cost and convenience, and is confronted only after having decided to travel from Chicago to Los Angeles. Accordingly, travel websites do not require customers to identify specific airports, but rather ask customers where they are coming from and where they want to go, then present them with possible itineraries involving nearby airports.

From an airport route network, two different types of air traffic networks can be examined at the metropolitan scale: route and origin-destination. A metropolitan area route network is simply a spatially aggregated airport route network in which the nodes are metropolitan areas, and the edges reflect the number of passengers that took off from city i and landed in city j. Because this type of network describes the actual physical movement of people from place to place, it is ideal for describing the diffusion things that people transfer through mere physical co-presence. For example, many have examined metropolitan area route networks to understand the long-range spread of influenza and other infectious diseases (e.g. Brownstein et al., 2006; Balcan et al., 2009a,b). This type of network has also been used to understand the urban economic externalities associated with handling large number of passengers, which can include employment in the wide range of services that exist to directly or indirectly facilitate air travel (e.g. baggage handlers, air traffic controllers) as well as taxes and fees assessed to passengers and carriers by airport operators, which in many cases are the local municipalities themselves (Button and Lall, 1999; Debbage and Delk, 2001; Neal, 2010). Indeed, some have even argued that high-volume airports can spur the development of city-within-a-city agglomerations of transportation-related services (Kasarda and Lindsay, 2012). Still others have linked cities with high air passenger volume to aspirations for, or achievement of, world city status (Keeling, 1995; Rimmer, 1998; Smith and Timberlake, 2001). Most broadly, having a high degree in the metropolitan area route network – a characteristic variously referred to in airline network studies as intermediacy (Fleming and Hayuth, 1994), absolute hub intensity (Derudder et al., 2007), or centrality (Preston, 1971) – is big business, often seen as yielding economic and status gains for cities.

A metropolitan area origin-destination network is defined differently: the nodes are still metropolitan areas, but the edges reflect the number of passengers that initially departed from city i and completed their journey in city j. Unlike the route network, this definition omits any connections and layovers in each passenger's journey; these are not part of the passenger's intended journey, but are merely inconveniences imposed by the airline industry's flight offerings. This difference impacts the interpretation of the network in two ways. First, whereas a route network treats people as passengers moving from point to point along a route, the origin-destination network treats people as intentional travelers purposefully arriving in and engaging with their destination cities. Thus, while a route network may be useful for assessing the effects of people *as air passengers* (e.g. boosting demand for baggage handling services), the origin-destination network is more useful for assessing the effects of people *as visitors* that engage with the local area (e.g. boosting demand for non-transportation services in the destination city). Accordingly, some have used origin-destination networks to examine the urban economic impact of terminally inbound passengers as opposed to passengers who are merely passing through. In network terms: such studies explore the consequences of having a high degree in the metropolitan area origin-destination network, a characteristic variously referred to in airline network studies as centrality (Fleming and Hayuth, 1994), relative hub intensity (Derudder et al., 2007), or local consumption (Preston, 1971). Many conclude that for urban economic growth in non-air transportation sectors, only the kinds of flows captures by an origin-destination network matter (Irwin and Kasarda, 1991; Neal, 2010, 2014).

A second impact of defining edges as origin-destination movements concerns the interpretation of what is flowing along the edges. Although this network is constructed from information about human movements, it implicitly also describes the movement of tangible and intangible resources passengers carry with them. For example, when passengers travel, they bring with them capital in the form of their purchasing power and information in the form of their ideas and tastes. Thus, the metropolitan area origin-destination network might be viewed as a proxy indicator for the movement of capital and information among cities. However, to be treated in this way, the omission of layovers and connections is critical. To the extent that passengers do transfer capital and information when they travel, they transfer it directly from their initial origin to their final destination, generally leaving minimal traces of these types of resources (except, perhaps, the cost of a quick meal) behind during layovers (Neal, 2010). Thus, other studies have used origin-destination networks not to explore questions of transportation or airlines, but rather to explore more general questions about