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Vulnerability of the European air transport network to major airport closures from the perspective of passenger delays: Ranking the most critical airports

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ABSTRACT

This paper analyzes the vulnerability of the European air transport network to major airport closures from the perspective of the delays imposed to disrupted airline passengers. Using an MIDT dataset on passenger itineraries flown during February 2013, full-day individual closures of the 25 busiest European airports are simulated and disrupted passengers then relocated to minimum-delay itineraries. Aggregate delays are used to rank the criticality of each airport to the network, with the possibility of disaggregating the impact across geographical markets. The results provide useful reference values for the development of policies aimed at improving the resilience of air transport networks.

1. Introduction

Air transport networks are vulnerable to external events, even those that only have a local impact. For example, a single airport closure due to poor weather conditions or an industrial action may affect the network's overall performance. The final impact can range from a few delays and missed connections to significant economic losses (Mazzocchi et al., 2010). One of the possible reasons behind this vulnerability is that ensuring resilient operations has been secondary to profit maximization and other geopolitical factors in airline network development during the last decades (Lordan et al., 2014b). On top of that, predicted rates of growth in air transport demand (ICAO, 2013) in combination with large shocks such as 9/11, or the 2010 Volcanic Ash Cloud, can reduce the ability to cope with such disturbances and put additional pressures on air transport networks (Cardillo et al., 2013). Within this context, reducing the vulnerability and improving the resilience of transport networks has been recognized by the European Commission as a high level goal for 2050 (EC, 2014a).

There is a decent body of literature on the resilience of air transport that largely employs complex network theory to analyse the topological properties of airline networks and their implications in terms of vulnerability to airport failures or the closure of air corridors. There is a disconnection, however, between these analyses and the actual impact of air transport disruptions on the final users (i.e. the passengers that experience travel delays). Indeed, only few of these studies consider the important aspect of how airlines relocate disrupted passengers and, to the best of our knowledge, no previous paper uses actual passenger demand data to that end. This situation contrasts with a richer literature in other modes, such as rail or

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road, where the analysis of resilience and vulnerability is more developed, and the implications in terms of direct cost to the user (e.g. travel delays) in the event of a disruption in service have been modelled in more detail (e.g. Jenelius et al., 2006).

Thus, this paper builds upon the concepts developed in previous studies with the objective to develop a new method to incorporate demand data into the assessment of vulnerability of the European air transport network to major airport closures. Using a Market Information Data Transfer dataset (commonly known as MIDT) on passenger itineraries during February 2013, full-day individual closures of the 25 busiest European airports are simulated and disrupted passengers are relocated to delay-minimizing itineraries where seat capacity is available. A multi-layered network is constructed, where airlines are only able to relocate passengers within their own alliances' flight networks. Vulnerability is measured by the aggregate delays imposed to the disrupted passengers. This allows us to rank the most critical airports in the European network. In addition, we can disaggregate the impact on geographical markets (with special focus on passengers travelling in routes within the European Economic Area, from now on "intra-EEA" routes). Information on how the traffic is redistributed under each scenario is provided as well, leading to an exploratory discussion on the main drivers of airport criticality. The results aim to complement the stream of literature that employs complex network theory to the same end and also provide useful reference values for the development of policies aimed to reduce the vulnerability and improve the resilience of air transport networks.

The rest of this paper is structured as follows: Section 2 provides a literature review on the analysis of resilience and vulnerability of air transport networks and discusses our contribution. Section 3 describes the supply and demand datasets. Then, the methodological process is explained, with particular focus on the passenger relocation algorithm. Section 4 presents the results and discusses their main implications. Finally, Section 5 summarizes our findings, addresses the limitations of our model, and proposes new paths for future research.

2. Literature review and contribution

2.1. Basic definitions

Vulnerability is a concept that is complementary to the ideas of resilience, robustness, or reliability (Reggiani et al., 2015). Rose (2007) defined resilience as the ability of a system to maintain functionality when disrupted, with particular focus on the speed at which the system returns to normal. Vulnerability was defined by Berdica (2002) as the "susceptibility of a system to experience disruptions that can affect its functionality". In the context of a transportation network, functionality can be understood as operability or serviceability, i.e. the possibility of using any node of link of the network during a given period. As noted by Jenelius et al. (2006), this definition of vulnerability can be linked to the general concept of risk and thus disaggregated in two components: (1) the probability of the disruptive event occurring, and (2) the consequences of the disruptive event (system damage). Given the difficulties in estimating the probabilities of extreme events, such as natural disasters or terrorist attacks, authors like Berdica (2002) or D'Este and Taylor (2003) argue that measuring the magnitude of consequences should be the primary focus of vulnerability studies. This leads to the concept of "conditional vulnerability", defined as the measurement of system damage given that the disruptive event occurs.

It is also possible to measure the criticality of a certain component of the system, such as any particular nodes or links. A critical component has a high probability of failure and creates a large amount of damage if removed. In parallel to above, ignoring the probability of failure in the analysis gives rise to the concept of "conditional criticality" defined by Jenelius et al. (2006), as the measurement of the damage caused by the failure of the relevant component.

2.2. Previous studies

The resilience and vulnerability of network systems have been areas of great interest because strategic economic sectors such as energy, utilities, transport, or telecommunications are dependent on networks to function. In regards to transport networks, Faturechi and Miller-Hooks (2015) list approximately 200 published works on a wide range of modes, including metro/subway systems (e.g. Derrible and Kennedy, 2010; Li and Kim, 2014; D'Lima and Medda, 2015); maritime transport (e.g. Berle et al., 2011; Thekdi and Santos, 2015: port operations; Ducruet et al., 2010: liner shipping; DiPietro et al., 2014: inland waterways); rail (e.g. De los Santos et al., 2012; Cacchiani et al., 2014; Rodríguez-Núñez and García-Palomares, 2014); road (e.g. Chen et al., 2002; Jenelius et al., 2006; Jenelius and Mattsson, 2012; El-Rashidy and Grant-Muller, 2014; Cats and Jenelius, 2015); air transport (covered below); and finally, there have also been attempts at developing models for intermodal resilient operations (e.g. Chen and Miller-Hooks, 2012).

After a comprehensive review of studies, Mattsson and Jenelius (2015) described two main approaches to measure vulnerability of transport networks: a) topological vulnerability, and b) system-based vulnerability.

In the topological vulnerability approach, the network is represented as an abstract graph and the researcher measures system damage as a result of changes in network topology after a disruption affects one or more nodes or links. This type of approach typically uses only supply data on available infrastructure and service frequencies. The topological properties of networks are characterised by indicators such as average shortest path or degree distribution, which determine how the network will be classified within a number of generic structures. The study of Zhang et al. (2015) analyses of 17 different