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Modelling the resilience, friability and costs of an air transport network affected by a large-scale disruptive event

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ABSTRACT

This paper deals with developing a methodology for estimating the resilience, friability, and costs of an air transport network affected by a large-scale disruptive event. The network consists of airports and airspace/air routes between them where airlines operate their flights. Resilience is considered as the ability of the network to neutralize the impacts of disruptive event(s). Friability implies reducing the network's existing resilience due to removing particular nodes/airports and/or links/air routes, and consequently cancelling the affected airline flights. The costs imply additional expenses imposed on airports, airlines, and air passengers as the potentially most affected actors/stakeholders due to mitigating actions such as delaying, cancelling and rerouting particular affected flights. These actions aim at maintaining both the network's resilience and safety at the acceptable level under given conditions.

Large scale disruptive events, which can compromise the resilience and friability of a given air transport network, include bad weather, failures of particular (crucial) network components, the industrial actions of the air transport staff, natural disasters, terrorist threats/attacks and traffic incidents/accidents.

The methodology is applied to the selected real-life case under given conditions. In addition, this methodology could be used for pre-selecting the location of airline hub airport(s), assessing the resilience of planned airline schedules and the prospective consequences, and designing mitigating measures before, during, and in the aftermath of a disruptive event. As such, it could, with slight modifications, be applied to transport networks operated by other transport modes.

1. Introduction

Generally, according to the Oxford Dictionary, the resilience of an object can be defined as its "ability to recoil or spring back into shape after bending, stretching, or being compressed" (http://complexworld.eu/wiki/Resilience_in_air_transport). In addition, Holling (1973) defined ecological resilience as the ability of a system to absorb changes in state variables, driving variables, and parameters, and still persist. In addition, Holling (1996) and Hollnagel et al. (2006) defined engineering resilience as the time required for a system to return to an equilibrium or steady state following a perturbation. Consequently, it can be said that the resilience of a given technical system generally implies its ability to operate under variable and

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unexpected conditions without substantially compromising its planned performances. As such, resilience can also reflect the robustness of the given system operating under disruptive conditions (Foster, 1993).

The above-mentioned concepts and definitions of resilience can also be applied to transport networks consisting of nodes, links, and the transport services connecting them. The nodes are usually transport terminals as the origins and destinations of transport services serving passenger and/or freight/goods flows. The links are the physical infrastructure (roads, rail lines, air routes, sea routes) stretching between nodes/terminals along which the vehicles perform transport services. While dealing with the resilience of transport networks, deterioration of the planned/scheduled transport services in terms of their delay and cancellation due to the impact of various disruptive events is commonly considered. The scale and scope of such deterioration under given affection reflect the resilience of the given network. In such context, the scale of changing resilience after removing (closing) particular nodes (terminals) and/or links (and services) represents the network's friability (Ip and Wang, 2011).

The disruptive events generally affecting transport networks can be extremely bad weather (dense fog, heavy rain and/or snowfall, hurricanes, tornadoes, etc.), usually unpredictable catastrophic failures of the transport network components, industrial actions of the transport staff, natural disasters (earthquakes, volcanos, tidal waves), traffic incidents/accidents and terrorist attacks. In some cases, these particular events can be interrelated and occurred simultaneously. The commonly affected actors/stakeholders are the network operators, i.e. providers of transport services and their users-passengers and freight/goods shippers/receivers. They are all usually imposed additional costs associated with deteriorated services, as well as recovery actions in the aftermath.

An air transport network consisting of airports and airline flights scheduled between them can also be affected by the above/mentioned disruptive events. Their impact often deteriorates the declared capacity of airports and air routes and consequently often causes very long airline flight delays and cancellations.

This paper aims at developing a methodology for assessing the resilience and friability of a given air transport network affected by a large scale disruptive event. In addition, it aims at estimating the consequences for particular actors/stakeholders involved – airports, airlines, and air passengers – which mainly include the costs of long-delayed and cancelled flights. As such, the methodology could be used for both a prior and a posterior forecasting and assessment of the consequences of particular impacts, respectively, and undertaking the appropriate actions for mitigating them using the "what-if" scenario approach. In such context, the prospectively affected airports, airlines and their passengers need to bear in mind that the time, scale and scope of impacts as the inherent properties of disruptive events cannot be influenced and/or prevented; in contrast, only their consequences can be dealt with.

In addition to this introductory section, this paper consists of four other sections. Section 2 describes the components and characteristics of an air transport network including the impacts of particular disruptive events. Section 3 develops a methodology for estimating the resilience, friability, and costs of the air transport network affected by a given (large scale) disruptive event. Section 4 provides an application of the proposed methodology. The final Section 5 summarizes some conclusions.

2. The air transport network

2.1. Components

An air transport network consists of airports as the network nodes and the air routes stretching between them as the physical links. There, airline flights controlled and managed by the ATC/ATM (air traffic control/management) system are carried out.

2.2. Resilience

2.2.1. Definition

The resilience of an air transport network is defined as its ability to withstand and stay operational at the required level of safety during the impact of a given disruptive event. This definition takes into account only the actions undertaken during the impact of the disruptive event and not the recovery actions aftermath (Chen and Miller-Hooks, 2012). However, in much wider context not embraced by the above-mentioned definition, resilience can generally be considered as static and dynamic. The former refers to the air transport network's capability to maintain its planned function during the impact of disruptive events. The latter implies the network's speed of recovering up to the desired (specified) state in the aftermath (Chen and Miller-Hooks, 2012; Rose, 2007). In addition, the resilience can be considered in the short-, medium-, and long-term (Njoka and Raoult, 2009).

In particular, the actions undertaken during the impact of the disruptive event on an air transport network considered in this paper commonly include significant reduction of the nominal/regular capacity or complete closure of the affected airports (nodes) and air routes (links) between them. This usually causes (rather long) delays and/or cancellations of the affected flights. Based on the nature of air transport operations, the impact of the disruptive event can spread wider to airports, air routes and flights that would otherwise be unaffected.