Transport Policy 28 (2013) 63–68

Contents lists available at SciVerse ScienceDirect

Transport Policy

journal homepage: www.elsevier.com/locate/tranpol

# Network resilience for transport security: Some methodological considerations

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ARTICLE INFO

Available online 24 October 2012

*Keywords:*
Network resilience
Transport security
Complex networks
Connectivity
Policy issues

ABSTRACT

This paper proposes a general conceptual framework which aims to integrate the concept of network resilience within that of transport security.

In particular, methodological reflections on the role of resilience vs vulnerability in connectivity network structures, such as scale-free networks, are highlighted. Operational measures of resilience are also outlined in order to enhance resilience in transport and communication networks.

Current policy strategies which focus on resilience show the relevance of this issue and the need for continuing research on the links between complex transport networks and resilience, mostly by exploring this relationship at different scale levels and its impact on the whole network.



## 1. Introduction

The socio-economic features that underlie infrastructure networks as well as the related patterns of development evolve in time and space in a very complex[1] way: "Societal functions are highly dependent on networked systems. Even the most basic day-to-day functions involve interaction with a variety of critical infrastructure systems" (Murray et al., 2008, p. 573). This is valid for transport, communication, energy, financial networks, etc. Currently, network infrastructures (supply side), as well as the intensity of (physical or virtual) flows associated with them (demand side), are becoming extremely important for public policy considerations, not only for evaluating the possible (dis)equilibrium (demand vs supply) points, but also for preventing intentional attacks, disasters and accidents. There is the need to study and analyse critical infrastructure systems, in order to better understand their operability and functionality, under severe disruption events.

The literature on critical network infrastructures, which explores the vulnerability/robustness to disruption, has grown considerably in recent years, demonstrating the relevance of this issue (see, e.g., Jen, 2005; Kim et al., 2010; Matisziw et al., 2009; Murray and Grubesic, 2007). In parallel, a number of different approaches (such as mathematical programming, general equilibrium models, simulation tools, etc) able to identify network vulnerability/fragilities have been investigated, approaches which also show the complexity of the related models and analyses (Matisziw and Murray, 2009; Rose, 2005).

It is clear that the importance of network infrastructure resilience is largely dependent on the location of its links and nodes, as well as on their connectivity. In this context, the type of topological relationships between the network nodes – combined with the analysis of the related economic weight/use – is a crucial issue worth examining, also taking on board the interesting recent contributions in social network analysis (Barabási, 2002). Understanding the (weighted) network topology of a transport/communication system poses some challenges, many of which stem from the complexity of the system, in connexion with the identification of the critical/vulnerable structures.

Starting from these considerations, in the present paper the relevance of the resilience concept – strictly linked to fragility – is examined, given its strong theoretical/analytical background, stemming from the bio-ecological sciences. In particular, after a brief account of the relationship between resilience and transport security (Section 2), there follows an overview of the definitions of resilience (Section 3), in order to subsequently focus on the issue of network topology and (the related) network resilience (Section 4). Next, some considerations on different resilience measures, as well as on possible policy options for enhancing resilience, with a view to improving transport security, are presented (Section 5). Finally, the concluding section offers some reflections on the resilience concept, its operability, and the relevance of its role in the policy strategies oriented to improve transport security, with particular attention to different scale analyses (Section 6).

## 2. Background: transport security and resilience

Transport security had become a fundamental issue in government policy. See, for example, the website of the UK Government

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[1] The fundamental feature of complexity can be identified as follows (Bossomaier and Green, 2000, p. 5): 'The essence of complexity is the outcome should not be obvious from the simple building blocks.' In other words, a complex system embodies the idea of non-intuitive and unpredictable behaviour, as already outlined by Simon (1962) p. 468: "Roughly, by a complex system I mean one made up of a large number of parts that interact in a nonsimple way." See also Reggiani (2012).

0967-070X/$ - see front matter 
http://dx.doi.org/10.1016/j.tranpol.2012.09.007

Department for Transport concerning Transport Security[2], where it states that: "The Department for Transport (DfT) aims to protect the travelling public, transport facilities and those employed in the transport industry, primarily from acts of terrorism. We aim to retain public confidence in transport security without imposing requirements that impact on the way they travel. The Transport Security team is also responsible for transport contingency arrangements in response to any actual or threatened disruption."

On the other side of the Atlantic, the Department of Transportation (DOT) at Washington, DC, on 26 November 2001, after the 9/11 terrorist attacks in the USA, provided guidance on response plans/ emergency support functions for transportation (for an overview and discussion on the response programmes in the various States in the USA after 9/11, see Parsons and Farradyne, 2002).

Clearly, transport and telecommunication systems – also as a result of their links with the economic and financial sectors – are extremely vulnerable to terrorist attacks.

In this context, it is interesting to note how in the first years of the 2000s prevention and protection were the central issues for critical infrastructure (National Research Council (NRC), 2002). Recently, the necessity to tackle complex systems data fusion/data mining, as well as integrating all hazard approaches and programmes (such as safety, security and emergency management sub-systems) has been emphasised (Federal Transit Administration (FTA), 2007).

In addition, the issue of a "quick layered response of the system with effective surge capability" has been included in the operational objective (Objective 4 below) in the framework of the following six goals for transportation security (Transportation Research Board (TRB), 2012):

1. social—involve the public, but this makes pre-operational surveillance riskier;
2. budget and policy—make risk-informed decisions the norm;
3. technical—focus on countermeasures and design (instead of vulnerabilities and threats) with dual benefits;
4. operational—quick, layered response with effective surge capability;
5. psychological
   - for those who are planning for attacks, transportation needs to be made a more difficult target;
   - for the public, peace of mind/acceptance of risk: security ≈ satisfaction;
6. Intelligence—support police/military/intelligence by having trained transportation employees report suspicious activities, and by making the bad guys stretch out their planning time.

The desired outcome is to ensure that an *integrated*, high level, all-hazard, national incident management system-responsive, multimodal risk management process is incorporated into major transportation agency programmes and activities. Clearly, the all hazards integrated approach (Federal Transit Administration (FTA), 2007) paved the way for the adoption of the resilience concept as the objective. At the Disaster Roundtables[3] held in Washington from 2001 to the present day (Transportation Research Board (TRB), 2012), we can see that two specific objectives deal with resilience:

(a) Creating a Disaster Resilient America: Grand Challenges in Science and Technology (Objective 12);
(b) Community Disaster Resilience (Objective 16).

Even though the resilience concept is often associated with natural disasters, the need to consider – in the US policy strategic actions – transport as a network integrated structure in order to create a resilient US organism to, among other things, terrorist attacks, has recently come at centre stage,[4] by enriching the original first goals of protection and prevention. This focus on resilience implies that the resilience concept should be analysed from both the methodological and empirical viewpoints. In this connexion, a basic framework in this respect will be presented in the subsequent sections.

## 3. Resilience: methodological reflections

"The etymology of the word "resilience" is the Latin verb "resilio", meaning to rebound" (Rose, 2009, p. 1). Starting with MacArthur (1955), the ecologists have investigated the properties of a number of different stability and stability-related concepts, for instance, the concepts of persistence, resilience, resistance, and variability: "Of these various concepts, the concept of resilience itself appears to have been rather resilient" (Batabyal, 1998, p. 235). In recent years, this concept has also been investigated, adopted, and applied in economics and the spatial sciences (for a review, see among others, Fiksel, 2006; Gibson et al., 2000[5]; Reggiani et al., 2002; Rose, 2009), by showing its potential in understanding the evolutionary paths of complex spatial systems.

There are two different ways of defining resilience (see Perrings, 1998, p. 505). One refers to the properties of the system near some stable equilibrium (i.e. in the neighbourhood of a stable focus or node). This definition, due to Pimm (1984), takes the resilience of a system to be a measure of the speed of its return to equilibrium. The second definition refers to the perturbation that can be absorbed before the system is displaced from one state to another. This definition, due to Holling (1973, 1986, 1992), does not depend on whether a system is at or near some equilibrium. It assumes that ecological systems are characterised by multiple locally stable equilibria, and the measure of a system's resilience in any local stability domain is the extent of the shocks it can absorb before being displaced into some other local stability domain. Perturbation may induce the system to change from one attractor (stability domain) to another, or not. If not, the system may be resilient with respect to that perturbation.

The first definition by Pimm, which is more 'traditional', focusses on the property of the systems near some stable equilibrium point (engineering resilience).

The second definition by Holling focusses on the property of the systems further away from the stable state (i.e. the size of the stability domain). The measure of resilience using this definition is the perturbation that can be absorbed before the system converges on another equilibrium state (ecological resilience).

The measurement of Pimm's resilience is therefore easier – from an empirical viewpoint – than Holling's resilience. However, it appears to be more 'restrictive', since it concerns only the equilibrium points, rather than the stability domains or basins of attraction. Moreover, we can observe that, on one hand, Pimm's resilience depends on the strength of the perturbation, while, on

[2] http://www.dft.gov.uk/pgr/security/.

[3] The Disaster Roundtable workshops are held two or three times a year and focus on a specific topic or issue. "Resilience and Recovery" is one of the common themes (see: http://dels-old.nas.edu/dr/).

[4] See also the words of President Barack Obama (27 August 2010): "I encourage all Americans to recognise the importance of preparedness and observe this month by working together to enhance our national security, resilience, and readiness" on the website of the recently established Community and Regional Resilience Institute (CARRI) in the USA: http://www.resilientus.org/.

[5] It is interesting to note that this article by Gibson et al. has been co-authored with Elinor Ostrom, the 2009 Nobel winner in Economics.