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Nogal Macho, M.; Honfi, D.

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Human actors, a system vulnerability or a capability for adaptation to enhance resilience of transport networks?

Maria Nogal[1*], *Dániel Honfi*[2]

[1]Faculty of Civil Engineering and Geosciences, Delft University of Technology, the Netherlands
[2]Division of Built Environment, RISE Research Institutes of Sweden, Gothenburg, Sweden
[*]Corresponding author: m.nogal@tudelft.nl

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1. Introduction

This research analyses the resilience of road transport networks, where human actors, that is, transport network users, are explicitly considered. Users of traffic networks are introduced in traffic analyses either as passive actors that suffer from the degradation of the traffic conditions, e.g., loss of reliability, loss of accessibility, etc., or as reactive actors, who modify their response as a consequence of the network disruption. The latter is the case of the traffic assignment models, where drivers adapt their choices to minimise their individual or global impact caused by traffic degradation. In both cases, human actors are vulnerable to traffic conditions.

The perspective of envisaging users as a part of the vulnerability of systems, e.g. of transport systems, is usually adopted by engineering assessments focusing on the technological domain of resilience, where users typically represent risks in terms of human safety, travel costs, or stress (Mattsson and Jenelius, 2015; Nogal et al., 2016). This contrasts with e.g. the studies on emergency and disaster management, which often consider humans as actors who make the system capable to improve resilience specifically in the social domain (depending on the scale and nature of people's interaction) (Paton, 1999; Lindbom et al., 2015). Indeed, introducing transport users only as vulnerability does not enable the exploration of the contribution of humans to overall system performance. As a result, the resilience of the system might be underestimated. It is, however, important to acknowledge that resilience is a complex construct, and disruption and recovery are affected by both the physical infrastructure and non-physical factors, such as human behaviour and decision making (Markolf et al., 2019). As Wang (2015) notes “humans are a key part of adaptive capacity of the system because they are the objects of movements in the system. They have to contribute their precious time and energy to make the trips happen”.

Further social aspects are discussed by Gajanayake et al. (2018), who show based on interviews, how community adaptation, i.e., the behaviour of users and operators and other relevant stakeholders, manages to decrease the impacts of disaster-related road failures, for instance by adjusting the demands to the changing conditions, thereby enhancing resilience as compared to a purely technological system. Moreover, a study of eight case studies on natural and man-made disasters focusing on transportation impacts (Kim et al., 2018) highlights, besides the centrality of transportation services in disaster management, that communications are essential to resilience building, moreover important role of social media, mobile communications devices, and distributed information technologies. This indicates the importance of a third domain of resilience, that is information management, discussed also by Nogal and Honfi (2019b).

This research work investigates on the actual role of human actors when the resilience of road transport networks is assessed, that is, to what extent they are considered as a system vulnerability or as a capability for adaptation of resilient transport systems. In that way, the main contribution of this research is that it connects the two perspectives, namely, the technological and social domains of resilience.

Emerging mobility systems are characterised by a change in user behaviour. Modelling the complex user's mobility patterns allows for the study of these systems and for a better understanding of how, for instance, car sharing schemes or autonomous cars will change the landscape in terms of vulnerability and resilience.

2. Methodology

This paper presents two traffic assignment models that introduce human behaviour to study the resilience of road networks. They are applied to the Luxembourg-Metz traffic network (see Figure 1) to investigate the potential of human actors to improve system performance.

The network models a section of the A31 highway in France. This highway accommodates average daily traffic of 100,000 vehicles and the freight transport to and from Luxemburg, Belgium, Netherlands and Northern Germany. The analysis has been conducted assuming 102 nodes, 278 links, and 150 routes between 10 OD pairs. Further details of this network can be found in Nogal and Honfi (2019a) and Nogal et al. (2019).

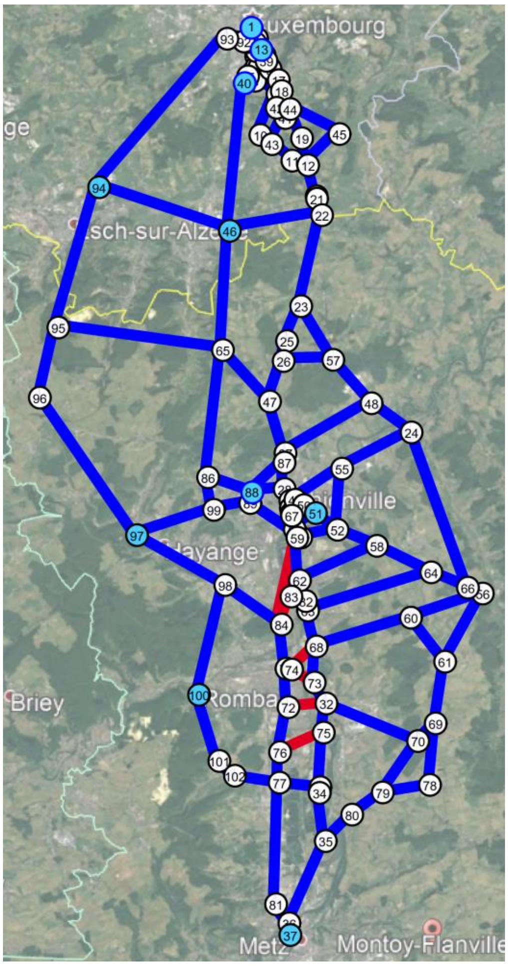

Figure 1: Luxembourg-Metz traffic network represented by their nodes and links. The shaded nodes represent origin or destination nodes and the dashed red lines depict the roads affected by a hypothetical disruption.

Nogal et al. (2016) propose a dynamic deterministic traffic assignment model (DDRE) that allows the day-to-day response of a road network when temporally affected by a disruptive event. Once the traffic network is restored, the model provides the recovery process of the traffic conditions. Based on the well-known Beckmann's User Equilibrium (Beckmann et al., 1956), this work introduces the so-called "restricted user equilibrium"', as it assumes that users, who do not have an infinite capacity of adaptation to changes and lack complete knowledge of the current situation, might not achieve the optimal situation where their travel times are the minimum associated with the existing conditions at each time interval. The authors assess the resilience of the traffic network by considering both, the cost generated by the disruption over time, and also the stress level of the users as a consequence of their attempt to adapt to the varying conditions. The rate of route change by users at each time interval is used to compute the stress of users. This work introduces for the first time a social aspect in the quantification of the resilience of traffic networks, that is, the discomfort of users that can result in traffic accidents. Nevertheless, it fails to consider the random nature of human decisions, because the average (deterministic) response of users is considered.

More realistic mobility patterns are modelled in Nogal and Honfi (2019a), where users' subjectivity when making their route choice (the perceived minimum travel time is not necessarily the actual minimum travel time) and the preferences to some routes that are objectively less appealing in terms of travel time, are introduced in a dynamic stochastic restricted equilibrium model (DSRE). The consideration of the variable response of users, which is captured by the stochastic approach, evidences that diversity in the user's reaction plays an important role in how the system responds to changes. Interestingly, in some scenarios, it has a positive impact either on the capacity of the system to adapt to the impact or on the recovery process. It is highlighted that the resulting improvement of the value of the resilience of the system is not related to the reactive attitude of vulnerable users who suffer a certain degree of discomfort. Instead, it is due to an intrinsic capability of the system to adapt.

3. Results and discussion

The influence of the two approaches mentioned, i.e., the DDRE and the DSRE, on the resilience assessment of the Luxembourg-Metz traffic network is discussed. Specific details of this network can be found in Nogal and Honfi (2019a) and Nogal et al. (2019). With this aim, a reduction of 83% of the capacity of the roads highlighted in Figure 1 is assumed, which starts at day 5 and finishes on day 8.

The deterministic approach proposed by Nogal et al. (2016) is analysed first. The cost generated by the disruption over time (Figure 2(a)) is combined with the stress level of the users (Figure 2(b)) to obtain the loss of performance shown in Figure 2(c). The last figure is used to determine the resilience of the system, accounting for the loss of performance of the system during the perturbation and the time required to fully recover, i.e., 19 days in this case.

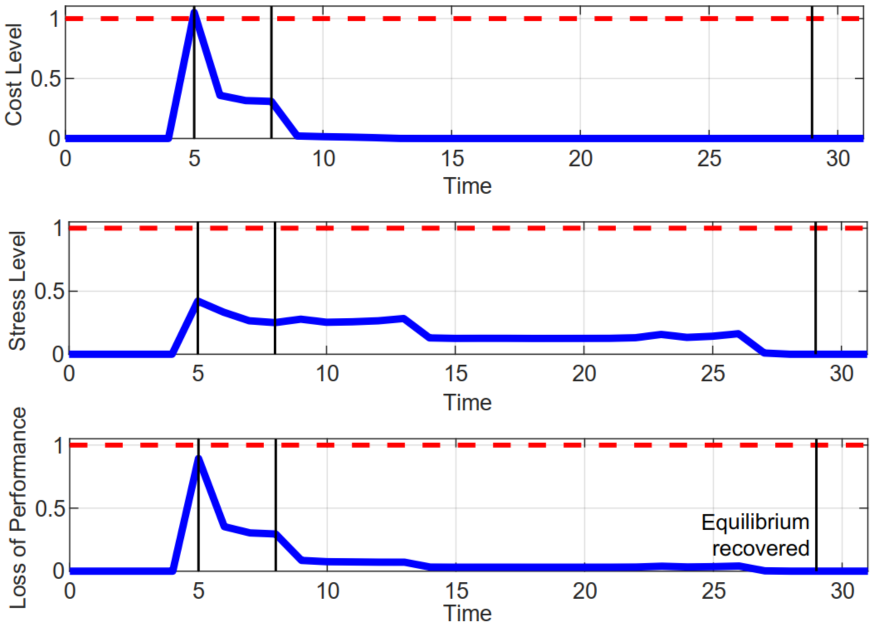

Figure 2: Resilience analysis according to the model proposed by Nogal et al. (2016).

It is noted that the cost level decreases when the users react and change their choices, increasing the stress level. If they are not able to accommodate to the degraded conditions (e.g., if no alternative routes exist), the cost level would remain constantly high during the time the disruptive event occurs, resulting in an important loss of performance and thus, low values of resilience. On the other hand, high stress levels, despite reducing the cost level, also result in important loss of performance and poor resilience indices. Therefore, the traffic system resilience assessment proposed here includes both the infrastructure network's inherent vulnerability, which is linked to the physical characteristics of the network, and the user's adaptation capacity, which is linked to social factors (e.g., similar previous experiences), and to information-related factors such the traffic information provided as well as its level of penetration.

When introducing the stochastic nature of human behaviour by means of the DSRE model, a large variety in the system response is found depending on the degree of users' subjectivity and dispersion through the network. As a result, significant differences in the cost and stress levels are identified. For instance, Figure 3 depicts two scenarios where different dispersion levels are considered. In this case, the main influence of the level of dispersion of drivers is observed in the recovery time. According to Nogal and Honfi (2019b), this response pattern is observed in those cases where the perturbation is located in a non-critical area of the traffic network with several alternative paths for users. Although in this case, the consideration of the stochastic user response improves the system resilience (compare Figures 2 and 3), , as pointed out by Nogal et al. (2019), this is not always the case, thus the role of human actors in the resilience of transport systems should be further investigated.

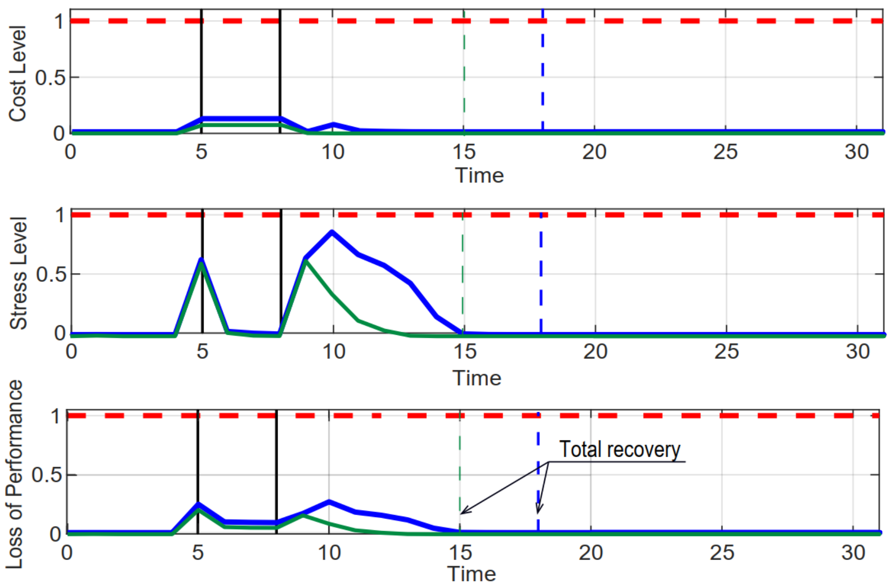

Figure 3: Different traffic responses given by the model proposed by Nogal and Honfi (2019a) associated with two dispersion levels.

Modelling traffic response by means of the deterministic approach (DDRE) implies that users have a reactive role. The reaction makes them suffer from stress. Therefore, the vulnerability of users increases the system vulnerability, thus reducing its overall resilience. This approach is significantly more complex than the approaches based on static models, which implicitly consider users as passive actors.

The stochastic approach (DSRE) involves both the vulnerability (i.e., the stress is considered) and a realistic adaptive capacity of users given by their ability to respond in different manners. As a result, the consideration of the stochastic nature of the problem evidences the capacity of users to improve the system performance over time, and thus the system resilience.

These results raise the question of to what extent the actual role of human actors in the overall traffic network performance is being dismissed, resulting, in some cases, in conservative estimations of the vulnerability and resilience of traffic systems.

4. Conclusions

It is widely accepted that to understand transport networks' performance, vulnerability, and resilience, the consideration of transport users is required. The main question here is how to model and assess their contribution. This research work has illustrated how the role of transport users varies from being purely considered as a vulnerability of the system to being another system capability able to adapt to the changing conditions. Thus, understanding the role of users in traffic models is of primary importance.

Traffic models that allow for users' capability to actively respond and adapt to traffic system changes, beyond the traditional view of human beings as passive/reactive actors, enables the assessment of the effectiveness and impact of different information management and coordination strategies.

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