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IFAC-PapersOnLine 49-3 (2016) 243–248

Capturing System-wide Magnitude of Earthquakes' Effects on Urban Traffic Networks

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Abstract: Transportation networks are one of the most important lifelines, designated to support societies even –if not especially- in cases of emergency. Though, the design and operations of the road infrastructure in metropolitan areas is typically based on demand assumptions reflecting either guided or equilibrated conditions. Even in cases of evacuation network modeling and planning, the demand scenarios typically considered fail to reflect the public's massive, sudden and abrupt response to the unexpected, as repeatedly reported in recent cases. The current paper offers possibly unique evidence of a system response on a significant nature-caused event and in particular that of the major earthquake in the metropolitan area of Athens, Greece, occurred in 1999. Detailed traffic data adequately covering Athens' road network are presented and thoroughly analyzed such as to provide quantitative information on system-wide traffic patterns in cases of such major events. The results aim to contribute valuable information that may facilitate the preparation of authorities responsible for civil protection, especially related to transport planning in cases of emergency.

Keywords: Urban Road Networks; Abrupt Circumstances; Earthquake; Traffic Patterns.

1. INTRODUCTION

In the last decades, urban traffic in Mega-Cities has become one of the most important research subjects, considering that urban areas strive with their growth in size and population. The objectives of typical development schemes of urban areas primarily aim at servicing average demand patterns while rarely particular emergency plans are conducted, especially addressing extreme and unexpected events. In order for such plans to be conducted, one of the key elements, that of the demand profile, must be defined. The treatment of demand in cases of emergency planning is based on rough estimates, typically critically transforming demand matrices and then estimating the effects and suitable countermeasures for addressing them (Sumalee and Kurauchi, 2006, Chang *et al*., 2010).

Demand patterns and system performance at the moment of a major natural disaster (or at the vital short period after its occurrence) significantly departs from conventional estimates and assumptions, since it is exposed to the generalized chaotic behaviour of panic, stress, threat and disorganization. The media coverage of such events, like the tsunami that struck Haiti in 2010 or the earthquake in Japan in 2011, gave evidence about the peoples' behaviour under the influence of a natural threat, where the aftermath in such cases is devastating.

Transportation systems, especially road traffic networks correspond to what is known as backbone lifelines, supporting society's safety and security in cases of such generalized emergencies, while their operational conditions may define the magnitude of effects that such phenomena may have on people and the economy (Khazai *et al.,* 2014)). In the current paper, a thorough investigation of the induced demand patterns of a significant earthquake occurred in a Metropolitan area is presented. In particular, the traffic patterns before, during and after the lethal earthquake of Athens, Greece, occurred at 14:56 on September 7, 1999 are presented and analysed, aiming to contribute to the experience related to the road networks operational characteristics and in particular in the magnitude of effects that such phenomena may have on traffic networks. The structure of the paper begins with a short literature review, while the next two sections offers illustrative evidence on the network-wide effects on traffic conditions during that event. Results from alternative comparative analyses are provided, covering both specific locations, but most importantly, as well as a system-wide depiction of traffic throughout the Athens road network. An important aim of the results analysis and the results is the exposure of the most relevant traffic variables that may sufficiently depict the overall

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Peer review under responsibility of International Federation of Automatic Control.
10.1016/j.ifacol.2016.07.041

system performance. The final section concludes and offer generalization remarks.

2. BACKGROUND REVIEW

Typical preparatory and emergency planning schemes in order for the transportation systems to cope with cases of large-scale and unexpected events such as natural disasters, rely on concepts related to reliability analysis and the methods deployed in order to assess the systems' operational characteristics under various scenarios and are properly designed to adequately respond, up to a desirable level, to alternative circumstances (Sumalee and Kurauchi, 2006, Dimitriou and Stathopoulos, 2007 and Dimitriou *et al.*, 2008a&b).

Nevertheless, the phenomena occurring during and right after major natural emergencies are reportedly completely different both in the cardinal assumptions used in typical transport and traffic models, mainly in the users/people behavior as well as their effect on system performance. In particular, Ranghieri and Ishiwatari (2014), provide evidence on the problems emerged during and after the Great East Japan Earthquake occurred in 2011, reporting specific problems and their consequent effects on peoples' safety by the transportation system disorganization. Similarly, Hara and Kuwahara (2015) further provided quantitative depiction of the traffic problems during the same event, utilizing GPS information by cellphones and probe cars. As it was reported in both analyses, one of the most crucial elements was the –understandable- demand 'explosion' and the chaotic phenomena that emerged, despite the fact that this extreme natural phenomenon occurred in the –evidently- most well prepared country for such cases.

Finally, designated guidelines for precautionary actions/plans are mainly aiming to the amelioration of the damages in the road networks or the optimal recovery planning such as to provide adequate operational conditions of the transportation system as soon as possible (Iida *et al.*, 2000, Chang *et al.*, 2010), while no particular attention is given on the optimal demand handling right after the major natural disasters. As it is revealed by this brief background review, no detailed evidence is presented related to cases of metropolitan area (that have distinctive characteristics compared to rural, recreational or those occurring in small cities) and the response of the transportation systems to such extreme challenges.

In the following section, a preliminary description of the network-wide traffic conditions in Athens during the day of the earthquake is presented, offering the reflection of a major earthquake on the traffic network.

1. DATASET PRELIMINARY DESCRIPTION

In Athens, Greece, in September 7, 1999, at 14:56, a major earthquake of R5.9 magnitude struck with an epicenter 17 km from the city's center, causing 143 deaths, significant property damages and significant economic and societal impacts. The paper presents a depiction of the traffic characteristics during that day, based on traffic data collected from 140 loop detectors, recording traffic flow (in vehicles/15 minutes) and the respective occupancy rates (in a range of 0 to 28). It is noted, that the earthquake occurred during the 60th 15-minute interval of that day (starting at 00:00).

In Figures 1(a)&(b), the flow counts for the day of the event are collectively presented. As it can it be observed, a sudden drop of most of the flow counts is registered right after the 60th interval, a clear sign of the development of a generalized gridlock (Oshima, 2013), since no specific damages were reported in any part of Athens major road system (nor primary or secondary road capacities were structurally affected by the earthquake).

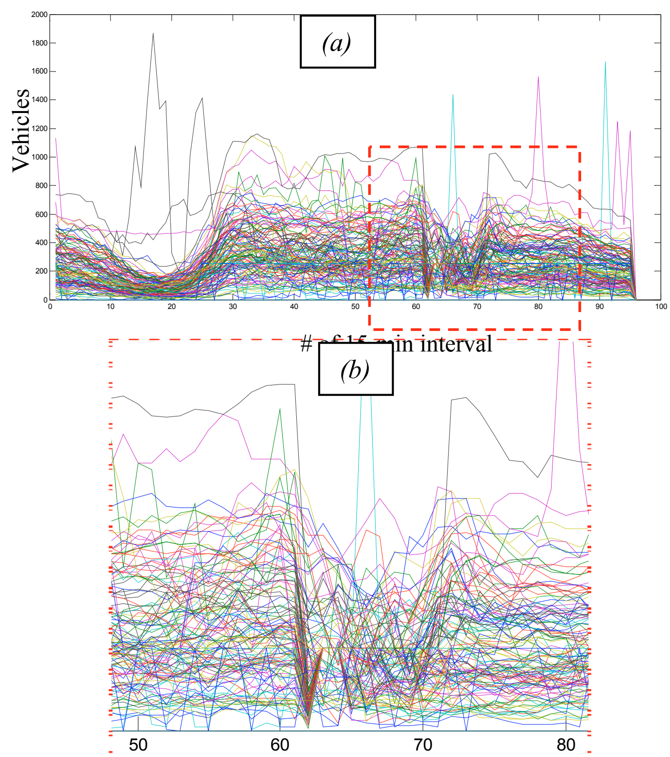

Fig.1: Diurnal series of traffic flow counts (a) and a close-up on the period right after the earthquake occurred (b) for the day 07.09.1999.

For comparative purposes, in Figure 2 shows the traffic counts plot for the day of 14th September, 1999, one week after the earthquake (here termed as the Business as Usual-BaU-day), depicting that the demand was equilibrated to -almost- normal conditions. The graph shows no generalized sudden traffic phenomena, apart from the standard isolated oscillations of traffic counts of no significant meaning.