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Impact analysis of transport network disruptions using multimodal data: A case study for tunnel closures in Stockholm

Athina Tympakianaki[a,*], Haris N. Koutsopoulos[a,b], Erik Jenelius[a], Matej Cebecauer[a]

[a] Department of Civil and Architectural Engineering, KTH Royal Institute of Technology, SE-100 44 Stockholm, Sweden
[b] Department of Civil and Environmental Engineering, Northeastern University, Boston, MA 02115, USA

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ABSTRACT

The paper explores the utilization of heterogeneous data sources to analyze the multimodal impacts of transport network disruptions. A systematic data-driven approach is proposed for the analysis of impacts with respect to two aspects: (a) spatiotemporal network changes, and (b) multimodal effects. The feasibility and benefits of combining various data sources are demonstrated through a case study for a tunnel in Stockholm, Sweden which is often prone to closures. Several questions are addressed including the identification of impacted areas, and the evaluation of impacts on network performance, demand patterns and performance of the public transport system. The results indicate significant impact of tunnel closures on the network traffic conditions due to the redistribution of vehicles on alternative paths. Effects are also found on the performance of public transport. Analysis of the demand reveals redistribution of traffic during the tunnel closures, consistent with the observed impacts on network performance. Evidence for redistribution of travelers to public transport is observed as a potential effect of the closures. Better understanding of multimodal impacts of a disruption can assist authorities in their decision-making process to apply adequate traffic management policies.

1. Introduction

Transportation networks in urban areas consist of a large number of components that are vulnerable to incidents and events, both natural and man-made. Some incidents may result in capacity reduction of specific links, disrupting their multimodal operations and the operations of the urban area (e.g. bridge collapses, tunnel closures), while others result in network-wide failures (e.g. adverse weather conditions). Incidents may also differ with respect to the amount of time available for response. This time dimension is very important and determines the type of strategies that may be used.

The importance of a robust and reliable transport system from an economic and quality of life perspective has led to considerable research in order to understand the mechanisms and interrelationships that create its vulnerability, and to find ways to mitigate the consequences of incidents (Mattsson and Jenelius, 2015).

In general, traffic management for incidents involves the following phases:

- *Preparedness,* which takes place prior to an incident with the aim to support and enhance response. Developing plans for dealing with different types of incidents is an important component in this phase.
- *Response and mitigation* which address the immediate and short-term effects of the incident, with the aim to reduce the impacts and speeding up recovery.
- *Recovery* which involves restoring services to a nominal state.

The increasing availability of traffic information enables a data-driven analysis as a direct approach for understanding the network dynamics and traffic patterns in response to specific events. A number of studies exist in the literature using data-driven approaches to analyze transport systems disruptions. Schäfer et al. (2002) utilized floating car data (FCD) from taxis for different cities. The analysis showed that the speeds can vary from the normal conditions, representing the traffic situation in case of special events, bad weather conditions or roadwork. Calabrese et al. (2010) used location inference from anonymous cell-phone data to analyze the spatial correlation between mobility choices of people and their origin patterns in the city of Boston during social events. Donovan and Work (2015) used GPS data from taxis to measure the resilience of the transport system in New York City to Hurricane Sandy. They analyzed the historical distribution of pace (travel time per mile) between various regions of the city, as well as the pace deviations during unusual events. In a similar context, Zhu et al. (2016) investigated recovery patterns based on taxi and subway ridership data in

* Corresponding author.
E-mail address: athinat@kth.se (A. Tympakianaki).

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New York City after hurricanes Irene and Sandy. The findings showed that the recovery behavior varies spatially and temporally. Melnikov et al. (2015) analyzed the impact on the road traffic performance of a major power outage in North Holland which disrupted the electricity-driven public transport system for several hours, and forced people to travel by car. Traffic flow and speed data were used to highlight the most affected areas during the blackout and the propagation of traffic jams compared with days with normal traffic patterns.

Most of the studies in the literature focus on the impact of various disruptions with respect to one measure, e.g. the road traffic conditions or taxi ridership. This paper uses a data-driven approach to provide a better understanding of the broader multimodal impacts of events related to important transport facilities that may become capacity bottlenecks. The systematic analysis can provide decision makers with the tools required to develop mitigation strategies which are comprehensive in their scope and deal not only with mitigating the impacts on car traffic but also the services provided by alternative modes.

For this purpose, heterogeneous data sources are utilized. The feasibility and benefits of combining historical traffic information from various data sources are demonstrated through a case study, which examines the impact of temporary closures, due to recurrent congestion, of a freeway tunnel. This subject has not received a lot of attention in the existing literature. Specifically, the study aims at understanding and quantifying the impacts of tunnel closures in two aspects: (a) road network traffic conditions, and (b) other transport modes, e.g. public transport. The broader questions that are addressed are:

- What are the impacts of tunnel closures on the network performance and demand?
- Are there wider impacts on the performance of other transport modes or redistribution of demand to other modes due to the tunnel closures?

The paper is organized as follows. Section 2 introduces the proposed data-driven approach for the analysis of disruption impacts on network performance and demand patterns. Section 3 presents a case study focusing on tunnel closures in Stockholm, Sweden and discusses the scope of the impact analysis and the various data sources that are utilized. In Section 4 the data-driven analysis is presented, summarizing the impact of tunnel closures on network performance and demand. Section 5 concludes the paper.

2. Approach

The proposed methodology utilizes extensive historical information obtained from multiple traffic data sources for the identification of the impacts of a network disruption. The approach focuses on events that are not planned in advance, but are a result of recurrent traffic congestion or incidents. Hence, people may not have sufficient time to adapt their travel plans to the new conditions. The approach can be divided into demand and network performance analysis supported by adequate traffic metrics from heterogeneous data sources.

2.1. Dimensions of evaluation

A significant, localized, network disruption such as a tunnel closure has direct impact on travel demand patterns as drivers try to find alternative routes to reach their destination or switch to other transport modes (Jenelius and Mattsson, 2015). In order to observe how vehicles are redistributed during a tunnel closure, *vehicle count measurements* near the tunnel entrance and at critical diversion locations can indicate changes in the demand towards specific paths compared to regular days without disruption. *Turning fractions* at critical diversion locations can provide insights about the alternative routes that drivers take during a closure.

Passenger load, boarding and alighting data for select public transport lines and stops around the tunnel can be compared between closure and regular days and inform about redistribution of demand to public transport.

Moreover, studying *taxi trips* may reveal changes in the demand for taxis on closure days. A hypothesis is that travelers, who usually use car for their trip, may shift to taxi to reach the nearest public transport station, if their home location is not accessible by public transport.

Redistribution of demand to alternative paths due to a disruption may affect network traffic conditions. The impact of detouring is expected to appear near the tunnel entrances and in a wider area farther away. Information about the extent in time and space of the impacts can be provided by *speed and travel time* measurements.

Broader impacts on the performance of other transport modes are also of interest. Potential impacts on public transport performance may include increased travel time for passengers, especially on routes that cross detouring paths during tunnel closures. Deteriorating service reliability is another potential impact. Information about such impacts can be provided by *bus travel time data*, and data on *headway distributions*.

2.2. Data sources

Advances in sensor technologies enable the collection of data that can be used for the analysis of complex network dynamics and mobility patterns. Traffic sensors may be categorized based on their functionality as point, point-to-point and area-wide sensors (Antoniou et al., 2011). A description of the data sources that can provide the aforementioned metrics to support the impact analysis of tunnel closures is presented below.

2.2.1. Point sensors

Point sensor technologies have been widely used for traffic data collection (e.g. inductive loop detectors, radar sensors). These sensors can provide accurate vehicle counts and average speed measurements per lane, usually in fine aggregation periods (e.g. 1-min interval). Moreover, turning percentages can be calculated if sensors are properly positioned.

2.2.2. Point-to-point sensors

Point-to-point sensors can be used to extract traffic information at the link or route level, depending on the location of the cameras. This type of sensor can be used to infer route travel times based on recorded timestamps of vehicles at the beginning and the end of the routes. *Automatic number plate recognition (ANPR)* systems are roadside cameras that use image processing to identify vehicles by recording their license plate. One example of such application is congestion pricing systems that are based on license plate recognition through video technology. Other point-to-point sensor technologies include Bluetooth and Wi-Fi sensors.

2.2.3. Area-wide sensors

The use of area-wide, non-infrastructure based sensors (in contrast to point or point-to-point sensors) is becoming more popular due to their potential to provide cost-effective spatiotemporal traffic and mobility information. These sensors are based on technologies such as Global Positioning Systems (GPS), and mobile phones. The network coverage includes the areas where GPS-equipped vehicles or mobile phones travel. The vehicles whose positions are tracked are called probe vehicles and the type of data is commonly referred as floating car data (FCD) (Rahmani et al., 2010). The raw data is processed to estimate the distribution of travel times and speeds for links in the network (Rahmani and Koutsopoulos, 2013; Jenelius and Koutsopoulos, 2013).

Vehicle fleets equipped with GPS are frequently used as an FCD source for the collection of traffic information. Information regarding the impact on the demand for taxis can be obtained by analyzing the number of taxi trips and their origin-destination patterns.