



Impact of weather conditions on macroscopic urban travel times

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ABSTRACT

Weather conditions may significantly impact a series of everyday human decisions and activities. As a result, engineers seek to integrate weather-related data into traffic operations in order to improve the current state of practice. Travel times and speeds are two of the elements of a transportation system that may be greatly affected by the weather resulting in deterioration of roadway network performance. This study aims to investigate the impact of different intensities of rain, snow and temperature levels on macroscopic travel times in the Greater London area (UK) during the period 1 October–10 December 2009. The analysis was carried out for three 2-h periods on weekdays during the morning, afternoon and evening periods. Automatic Number Plate Recognition (ANPR) data obtained from more than 380 travel links are used in the analysis. The main finding is that the impact of rain and snow is a function of their intensity. Specifically, the ranges of the total travel time increase due to light, moderate and heavy rain are: 0.1–2.1%, 1.5–3.8%, and 4.0–6.0% respectively. Light snow results in travel time increases of 5.5–7.6%, whilst heavy snow causes the highest percentage delays spanning from 7.4% to 11.4%. Temperature has nearly negligible effects on travel times. It was also found that the longer links within outer London generally yield greater travel time decreases than those in inner London, and even higher decreases than the shortest links in central London. This research provides planners with additional information that can be used in traffic management to modify planning decisions and improve the transportation system control on a network scale under different weather conditions. In order to determine whether the weather effects are region-specific, continued research is needed to replicate this study in other areas that exhibit different characteristics.

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1. Introduction

Travel times and speeds are two traffic parameters of a transportation system that may be greatly affected by the weather, resulting in deterioration of a network's performance (Koetse and Rietveld, 2007). Especially inclement weather conditions may result in substantial reductions of roadway capacities and thus, operating speeds (Martin et al., 2000; Koetse and Rietveld, 2009). Additionally, traffic demand may be largely affected by the weather, since the latter has a considerable impact on a series of human decisions such as transport modal choice, trip distribution, trip cancellation or postponement; altering roadway users' valuation of actual transport costs and travel times (Koetse and Rietveld, 2007, 2009).

Considering the significant impact of weather conditions on the transportation system and its performance, engineers are seeking to integrate weather-related data into traffic operations in order

to improve the current state of practice. Agarwal et al. (2005) states in his report that “nearly all traffic engineering guidance and methods used to estimate highway capacity assume clear weather. However, for many northern states, inclement weather conditions occur during a significant portion of the year”. For example, the Highway Capacity Manual (HCM) (TRB, 2000) suggests that free-flow speed on freeways is reduced by 9.7 km/h under light rainfall and by 19.3 km/h in heavy rain, without, nonetheless, explicitly defining rain intensity ranges. Potential incorporation of weather information into guidelines prerequisites a thorough understanding of how traffic conditions vary both spatially and temporally under different weather conditions. The separate analysis and exploration of the effects of different weather conditions on every urban or rural transport network is essential for local authorities to better understand the network's performance (Smith et al., 2004; Koetse and Rietveld, 2009). This task is of some importance taking into consideration the substantial variability among past research results that mainly depend on the target area, geometric, traffic and drivers' characteristics, socio-economic factors, the roadway functional class, the season of the year and the climate of the examined region (Smith et al., 2004; Wang et al., 2006; Koetse and Rietveld, 2007).

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For example, the literature indicates that 'rain intensity matters' (TRB, 2000; Smith et al., 2004; Maze et al., 2005; Hranac et al., 2006; Wang et al., 2006) by affecting congestion and travel times; however, the reported speed reductions vary considerably. The estimated range of speed decrease due to light rain is roughly 2–10%. Ibrahim and Hall (1994) stated that light rain caused a drop in free-flow speeds of 5–10 km/h at two sites in Mississauga (Ontario), while Hranac et al. (2006) estimated free-flow speed and speed-at-capacity decreases of 2–3.6% and 8–10% respectively in Baltimore, Twin Cities, and Seattle. Unrau and Andrey (2006) found that speed dropped by approximately 10% on an urban expressway in Toronto (Canada) during daytime uncongested conditions and light rain.

The corresponding drop in travel time attributed to heavy rain is generally higher and ranges between 4% and 20%. For instance, Stern et al. (2003) examined several roadway segments in Washington DC resulting in an average travel time increase of 14% during adverse weather conditions, while 17% of the examined cases yielded travel time increases greater than 20%. Agarwal et al. (2005) estimated freeway speed decreases of 4–7% during heavy rain (6.35 mm/h) for an area in the Twin Cities, Minnesota. Wang et al. (2006) examined an urban area in Nagoya City (Japan) concluding that an average speed decline of 6.03 km/h occurred during heavy rain and also the size of the weather effects was highly contingent with roadway characteristics, such as roadway class and number of lanes. Smith et al. (2004) indicated that light and heavy rain yield statistically different speeds when compared to 'no rain' conditions, but unlike other studies, there was no statistical evidence of that difference.

Likewise, a common finding on a global scale is that snow has the worst impact and diverse effects on travel times. Ibrahim and Hall (1994) estimated drops in free-flow speeds ranging 38–60 km/h, while Kyte et al. (2001) reported speed declines due to snow by up to 16 km/h. Agarwal et al. (2005) estimated speed decreases of 11–15% under heavy snow conditions (>12.7 mm/h) and Maze et al. (2005) corresponding decreases of 4–13%. In 2006, Hranac et al. showed that speed decreases during light snowfall from 5% to 16%, whilst heavy snow caused reductions spanning from 5% to 19%. Sabir et al. (2008) found that snow has a negative impact on speeds of approximately 7%. The previous findings explain the diversity in spatio-temporal weather effects on travel speeds. Although the estimates amongst studies are difficult to compare in magnitude, the impact of rain and especially snow on traffic speed at congested links during rush hours appear to be significant (Knapp et al., 2000; Sabir et al., 2008). Additional insights into the magnitude of weather impact on network travel times are necessary in order to make more accurate assessments and provide additional information to traffic managers (Agarwal et al., 2005; Koetse and Rietveld, 2009).

This task was particularly challenging in the past due to the lack of weather and traffic data of high spatial granularity (Sabir et al., 2008). Older studies (Botha and Kruse, 1992; Parsonson, 1992) were highly based on manual traffic counts and weather data that were obtained from a limited number of weather stations. Numerous subsequent studies utilised data from single or dual loop detectors and automatic traffic counters (Kyte et al., 2001; Smith et al., 2004; Hranac et al., 2006; Unrau and Andrey, 2006; Hablas, 2007). Presently, the technological advancements in data collection and management, infrastructure, software and hardware, as well as the extensive application of Intelligent Transportation Systems (ITS) can facilitate such analyses by broadening the target areas.

In addition to the above, the temporal resolution of the data has substantially improved in the last two decades. The review of past studies reveals that the granularity of both weather and traffic data typically ranges between 5 min to a few hours (Ibrahim and Hall, 1994; Hablas, 2007). Bluetooth, cell phone and GPS devices have

attracted significant attention over the last years providing travel time and/or speed data on a per second interval or even less (Wang et al., 2006). Similarly, recent meteorological studies that examine weather satellite and radar technologies, have substantially improved the data granularity at the level of some seconds (Heinselman and Torres, 2011; Sutherland-Stacey et al., 2011); yet their utilisation in the transport field remains somewhat limited.

This paper attempts to address some of the shortcomings derived from the literature. One of the main limitations is that a large quantity of studies focuses on a limited number of routes or roadway segments, mainly due to a lack of data (Ibrahim and Hall, 1994). Limited research examines the performance of a transportation network at a state, city or even trip level (Sabir et al., 2008). Potential generalizations of the findings stemming from a roadway-level analysis would have to consider roadway characteristics and other contextual factors. On the contrary, transportation management agencies would benefit more from knowing the effects of the weather on the transportation network of greater geographical regions (e.g. central, inner and outer London). This may be better understood by reckoning that planning decisions and traffic control modifications are usually being applied within or on the periphery of large areas in urban systems (e.g. London) rather than on individual links.

Another drawback is that the majority of the research works engage with uncongested and/or rural freeways and expressways (Smith et al., 2004; Agarwal et al., 2005; Maze et al., 2005; Wang et al., 2006). It is worth stating that the quantification of weather effects on urban travel times poses many challenges. Urban links are usually shorter in length than rural roads, they exhibit lower operating speeds and carry more interrupted traffic due to pedestrian crossings and signalised intersections. However, the outcomes of a macroscopic study that focuses on a large urban area consisting of several travel links may offset the previous constraints. It may also provide valuable information to practitioners about the network's behaviour and not solely about links that carry a small percentage of the network's traffic. Furthermore, a large number of studies focus on extreme weather conditions (Botha and Kruse, 1992; Parsonson, 1992; Ibrahim and Hall, 1994; Bernardin et al., 1995; Hofmann and O'Mahony, 2005; Hablas, 2007; Martin et al., 2000; Koetse and Rietveld, 2009). This research differs from previous works on the consideration of different intensities of precipitation, snow and temperature levels, rather than simply examining the presence or absence of inclement weather conditions. Also, very few studies have looked at regional differences associated with inclement weather impacts on free-flow speeds (Hablas, 2007). Finally, the effects of weather variability on travel times or speeds have not been documented to a large extent, especially when compared to numerous studies dealing with the impact on traffic flows (Hanbali and Kuemmel, 1993; Al Hassan and Barker, 1999; Parry, 2000; Smith et al., 2004; Keay and Simmonds, 2005), and accidents' frequency and severity (Welch et al., 1970; McDonald, 1984; Stern and Zehavi, 1990; Maycock, 1995; Edwards, 1996; Andrey et al., 2003; Eisenberg, 2004; Shankar et al., 2004; Hermans et al., 2006).

1.1. Purpose and objectives

The goal of this study is to investigate how precipitation, snow and temperature affect macroscopic urban travel times in the Greater London area, UK. The first objective is to examine spatio-temporal correlations of rainfall data. The results of this preliminary analysis serve as the basis for the selection of the examined travel links that form larger regions around each weather station. The second focus is to compare the effects of different intensities of rain, snow and temperature levels on travel times, during the morning, noon and evening period. The exploration of how the above impact varies among central, inner and outer London constitutes the third target. Finally, the results of the preceding analysis

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