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To travel or not to travel: 'Weather' is the question. Modelling the effect of local weather conditions on bus ridership

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ABSTRACT

While the influence of weather on public transport performance and ridership has been the topic for some research, the real-time response of transit usage to variations in weather conditions is yet to be fully understood. This paper redresses this gap by modelling the effect that local weather conditions exert on hourly bus ridership in sub-tropical Brisbane, Australia. Drawing on a transit smart card data set and detailed weather measurements, a suite of time-series regression models are computed to capture the concurrent and lagged effects that weather conditions exert on bus ridership. Our findings highlight that changes in particularly temperature and rainfall were found to induce significant hour-to-hour changes in bus ridership, with such effects varying markedly across both a 24 h period and the transit network. These results are important for public transport service operations in their capacity to inform timely responses to real-time changes in passengers' travel demand induced by the onset of particular weather conditions.

1. Introduction

Public transport plays an essential role in maintaining civic and economic activities by providing a mass and sustainable mobility option for urban populations (Schwanen, 2002; Vuchic, 2005; Cervero, 1998). As such, public transport services by and large need to operate in a manner that passengers' travel needs are adequately met ranging from everyday commuting to less routinised, more spontaneous trips. In this regard, the role weather plays in influencing the level of public transport service and ridership has been highlighted as an important issue in transport scholarship (Guo et al., 2007; Böcker et al., 2013). Inclement and extreme weather conditions (e.g., heavy precipitation, low temperatures and strong winds) are known to have the capacity to degrade service quality (e.g., disrupting service schedule) and passenger experience (e.g., prolonged waiting and travel times), with the potential to induce temporary as well as long term declines in ridership (Hofmann and O'Mahony, 2005; Changnon, 1996; Hine and Scott, 2000). As such it is important for us to consider the way in which weather impacts the everyday operation of public transport systems such that its negative effects and potential loss in ridership can be ameliorated. To achieve this, the effects that weather impose on public transport ridership first need to be understood to provide the necessary evidence from which planning and operation strategies can be founded (Guo et al., 2007; Böcker et al., 2013).

Given the need to understand the effects of weather on public transport and its end users, a growing number of recent studies have sought to examine the relationship between weather and ridership, e.g., Changnon (1996), Hofmann and O'Mahony (2005), Guo

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et al. (2007), Kalkstein et al. (2009), Arana et al. (2014), Singhal et al. (2014). Their findings highlight that public transport (e.g., bus and rail transit) ridership is negatively influenced by heavy precipitation, and to a lesser extent, high temperatures, strong winds and high levels of humidity (Böcker et al., 2013; Koetse and Rietveld, 2009). In addition, the effects of weather on ridership have also been shown to significantly vary across different calendar events and transit modes. For example, in a Chicago-based study, Guo and colleagues (2007) found that changes in weather conditions exerted greater impact on metro and bus transit ridership during weekends than weekdays; and metro ridership was less affected by weather than bus ridership, possibly due to the experience of riding a bus is more exposed and vulnerable to inclement weather. Similar findings were reported by Cravo et al. (2009) and Kashfi et al. (2013) in studies of New York City and Brisbane (Australia) respectively. Focusing on two cities in Canada, Trépanier et al. (2012) found that weather had stronger effects on senior passengers; and adverse weather might drive a modal shift from bus to rail transit among public transport passengers. Finally, Singhal et al. (2014) explored hourly relationships between weather and ridership for the New York metro system on weekdays and weekends. Their study revealed that a number of weather variables including the presence of rain, snow and strong winds to be negatively associated with the metro ridership especially during weekends.

While not exclusively focusing on public transport, some other transport studies have also shed light on the impact of weather on people's public transport use under the broader umbrella of travel behaviour. In two linked studies, drawing on the Swedish National Travel Survey data, Liu et al. (2015, 2016) modelled the impacts of weather conditions (in particular, temperature, precipitation and a measure of thermal comfort) on modal choice and trip-chaining behaviour along with a suite of other contextual factors (e.g., household size, income, car ownership and population density). After accounting for the influences of contextual factors, their findings indicate that weather conditions, particularly precipitation exerted significant effects on public transport use, which were shown to vary significantly across different seasons and locations across Sweden. For example, heavy rain was found to discourage bus use in the northern Sweden during summer, autumn and winter, whilst the reverse was shown to be the case for southern locales in the country (Liu et al., 2015). Such findings imply the existence of seasonally varying and localised perceptions of people towards weather, which contribute to a variety of behavioural responses (e.g., whether to take public transport or not) to weather of people across Sweden. In another related study, Creemers et al. (2015) investigated the relationships between modal choice behaviour and an array of hourly as well as lagged weather variables (e.g., temperature, fog, precipitation and a measure of thermal comfort) in the Netherlands, wherein only a thermal comfort, namely, physiologically equivalent temperature (PET), was found to have a significantly negative effect on bus usage.

Despite the accumulating evidence of weather's effect on public transport ridership, their relationships have arguably yet to be fully understood. In particular two research gaps can be identified. First, close scrutiny of the current transport literature reveals that real-time relationships between weather and public transport ridership has seen scant scholarly attention. A commonly adopted approach to investigate the weather-ridership relationship has been the use of daily averages of weather measurements (e.g., the mean daily temperature and main daily rainfall) as exogenous variables on which system-wide daily ridership is modelled, see for example studies by Guo et al.(2007), Kalkstein et al. (2009), Arana et al. (2014). While adopting this analytic strategy is able to establish certain weather-transit associations usually at the system-wide level, this daily-based approach is not able to fully capture the concurrent response of ridership to changes in weather conditions. As weather is known to have the potential to be highly variable over relatively short periods of time (Ephrath et al., 1996; Mapes et al., 2003), the resulting impact on transit ridership may vary accordingly. Only a limited number of studies including Singhal et al. (2014) and Creemers et al. (2015) have begun to examine the real-time impact of weather on transit ridership (e.g., hourly variations in bus ridership). How weather conditions are known to affect people's daily travel behaviour, however, remains to be addressed by transport scholars (Creemers et al., 2015). Furthermore, the lack of evidence on the real-time weather-ridership relationship at finer temporal scales arguably limits their utility for public transit operators in terms of how the findings can be translated to adjustments to service and account for weather induced variations in transit ridership.

Second, although most existing studies that have examined the weather-transit relationship have focused on its temporal variability, the geographic dimension remains largely unexplored. Studies by Liu et al. (2015, 2016) are among the few exceptions that have examined the spatial heterogeneity of weather's influence on travel behaviour. However, these studies both adopted a relatively coarse spatial scale (municipalities) with the effect of limiting the capacity to reveal intra-metropolitan weather-transit ridership patterns. Tao et al. (2016), on the other hand, adopted a suite of geo-visual techniques to unveil spatially varying patterns of bus usage across Brisbane, Australia. This scarcity of the evidence on the spatial variation of weather-travel relationship is despite a growing body of research that shows that people tend to exhibit systematically varying trip-making patterns according to trip distance, frequency and modal choice across urban areas, associated with different physical (e.g., density and design) and social (e.g., income level and household type) structures (Bagley and Mokhtarian, 2002; Wang and Khattak, 2013; Morency et al., 2011). Furthermore, urban spaces are comprised of a mosaic of spatially segregated locations, each with distinct functionalities (e.g., office, commercial and education) and activities with particular patterns (e.g., routinized non-discretionary versus recreational and discretionary activities) (Chapin, 1974; Handy et al., 2002; Ibrahim, 2003). Given what we know of both individual travel behaviours and urban form, it is likely that public transport passengers travelling from and bound for different localities across a city may also exhibit collectively different levels of vulnerability to changing weather conditions. Hence, there is a need for transport scholars to begin to understand the geographic dynamics of trip patterns in particular origins and destinations (Tao et al., 2016; Liu et al., 2016). Furthermore, revealing weather-transit ridership at finer temporal and spatial scales will also provide a necessary evidence base that allows transit operators to impose proactive adjustment in scheduling and resourcing a transit network especially when adverse weather conditions hit. This, in turn, has the potential to enhance transit users' travel experience as well as achieve enhanced performance of transit operators.

This study aims to address these research gaps through a spatio-temporal examination of the weather-transit relationship. To this