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The influence of weather on local geographical patterns of bus usage

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ABSTRACT

This paper broadens the research on weather and public transport usage by considering the micro dynamics of the effect that various weather conditions impose on micro geographic patterns of bus ridership in Brisbane, Australia. A smart card data set and detailed measurements of weather, allied with a suite of statistical and visual analytic techniques, are employed to capture the effect of weather on the local variations of bus ridership. While changes in weather conditions do not significantly affect bus ridership at the system level, some marked influence was found for rainfall, wind speed and relative humidity at a sub-system level. In addition, discernible variations of both the magnitude and direction of weather's effect were found at the sub-system level. Developing a more geographically detailed understanding of the effect of weather on public transport services serves as a critical first step towards establishing a more weather-resilient public transport system. This new understanding has the potential to contribute to an evidence base that can be used to proactively adjust public transport services in response to changes in weather conditions across different parts of the network. Further research is needed to assess how transferable our findings are to other public transport and climatic contexts.

1. Introduction

Transport and weather are intrinsically linked. Motorised transport in particular has been highlighted as a key sector contributing to greenhouse gas emissions and global warming (Chapman, 2007), with some research and reports claiming that climate change might bring about marked changes in our future daily weather patterns in a variety of ways, including increases in the number of severe weather days (IPCC, 2014; Hansen et al., 2006). Transport is also an integral part of our everyday life and subject to the influence of variations in weather conditions (Böcker et al., 2012; Koetse and Rietveld, 2009). We already know that inclement weather such as heavy rain and snow aggravates traffic congestion and causes increases in the number of incidents with the effect of degrading the operational efficiency of transport systems (Al Hassan and Barker, 1999; Call, 2011; Rakha et al., 2008). At an individual level, people's trip-making decisions have also been found to be influenced by weather conditions resulting in trip rescheduling, re-routing and cancellation (Cools et al., 2010; De Palma and Rochat, 1999; Sabir et al., 2010). It therefore follows that the operation and management of transport systems needs to consider daily variations of weather conditions to enhance resilience and operational efficiency of transport systems in response (Koetse and Rietveld, 2009; Kim et al., 2013).

Weather is capable of impacting public transport systems in a variety of ways including causing delays in delivering public transport services and making the experience of using public transport less comfortable (for example, waiting for a bus in the rain), therefore potentially reducing ridership (Changnon, 1996; Hine and Scott, 2000; Hofmann and O'Mahony, 2005). Understanding the influence of weather on public transport and particularly its impact on passengers' trip-making behaviours therefore has potential to help improve public transport services by better meeting passengers' travel needs under different weather conditions (Arana et al., 2014; Guo et al., 2007; Kalkstein et al., 2009). Achieving this goal is of particular value given that many cities around the world have shown increasing interests to promote public transport use in order to pursue an overall more sustainable transport system (Cervero, 1998; Banister, 2011; Currie and Wallis, 2008).

While some research has focused on developing an empirical understanding of the weather-public transport usage relationships, few studies have examined the geographic dimension. The scarcity of research in this area arguably calls for more attention especially given the strong spatial variations of both weather conditions (Hidalgo et al., 2008; Stewart and Oke, 2012; Theeuwes et al., 2014) and patterns of people's daily trip-making behaviours (Wang and Khattak, 2011; Tribby and Zandbergen, 2012; Salonen and Toivonen, 2013) and their interplay across a metropolitan area. As such it follows that weather conditions

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exert some notable influence on public transport and this influence varies across space. Thus, capturing the micro geographic patterns of public transport use in relation to variations in weather conditions has potential implications for prioritising public transport operation and management, for example, adjusting service frequency during a prolonged period of heavy rain.

This study redresses the identified gap through an empirical examination of the geographic patterns of weather influencing public transport ridership. We take the bus network and its use in metropolitan Brisbane, Australia, as a case study. Drawing on a large smart card dataset and detailed measurements of weather conditions, we pay attention to three particular questions:

- Do variations in weather conditions bring about shifts in bus ridership?
- Is the effect of weather conditions on bus ridership homogeneous across the bus network?
- Do variations in weather conditions create geographically discernible patterns of ridership within the bus network?

These questions are investigated using a suite of statistical and spatial analytical techniques to produce outputs that might inform the planning and operation of a city's bus services.

The rest of the paper is structured as follows: Section 2 provides the theoretical background before introducing the study context and data sources in Section 3. Section 4 presents the analytic methods and results. Section 5 discusses the implications of the results for public transport management and policy in conjunction with identifying avenues for future research before drawing a set of tentative conclusions.

2. Theoretical background

By combining theories in transport geography (e.g., time geography by Hägerstrand (1970)) and socio-psychology (e.g., the theory of planned behaviour by Ajzen (1991)), Van Acker et al. (2010) proposed an integrated conceptual model that describes the decision hierarchy that underpins an individual's travel behaviour (e.g., driving or taking public transport to work). According to this model, an individual's travel behaviour is subject to both reasoned (e.g., attitudes, preferences) and unreasoned (e.g., habits, impulsiveness) influences, which sit at the centre of the decision hierarchy. Such psychological decision process is then situated within a broader social (relating to one's social network, household compositions) and spatial context (relating to a city's built environment and infrastructure characteristics) that offers certain opportunities but also imposes specific constrain on an individual's travel behaviour decisions (i.e., where, when and how to make a trip).

With the model by Van Acker et al. (2010) in mind, weather has been shown to have the potential to interface with individuals' attitudinal factors as well as the broader social and spatial context that may affect their travel behaviours. First, weather was found to exert evident impact on the spatial context of travel behaviour. For example, some researchers have found that adverse weather such as snowfall resulted in heightened hazards and reduced road speed compared to non-snow days (Al Hassan and Barker, 1999; Rakha et al., 2008; Call, 2011), thus reducing the accessibility of certain destinations for travellers. Under such circumstances, changes in travel decisions including rescheduling, rerouting or cancelling trips were observed (De Palma and Rochat, 1999; Cools et al., 2010). Second, concerning attitudinal factors, scholarship has revealed that people exhibited less preference towards active transport options than other forms of transport (in particular, private vehicles and public transport such as bus and train) during wet periods (Aaheim and Hauge, 2005; Sabir et al., 2010). In addition, Khattak and De Palma (1997) revealed that car users were reluctant to switch to using public transport (in particular, bus) during raining periods given the potential of getting wet and feeling cold while waiting for buses. Last, the influence of weather on travel behaviour has been found to differ across different socio-demographic groups. For example, in a Belgian study, Khattak and De Palma (1997) found that commuters with children were less likely to change their travel patterns under inclement weather due to their household responsibilities.

Despite the relevance of weather to the various aspects of individuals' trip-making decisions and behaviours, only a limited number of studies have investigated its influence on people's use of public transport (Guo et al., 2007; Hofmann and O'Mahony, 2005). For example, in a Chicago-based study, Changnon (1996) revealed a slight decrease of ridership of mass transit (3–5% for bus and 2.1% for train) associated with summer rainfall during weekdays. Within the same study context, Guo et al. (2007) highlighted that bus trips on weekends were more affected by adverse weather than weekday trips; and rail trips in general were less affected by weather compared to bus trips. Arana et al. (2014) found that occasional bus users were more influenced by weather than more frequent users on weekends (in particular, Sundays). In another related study, Kalkstein et al. (2009) found that across three urban areas (Chicago, the San Francisco Bay Area and Northern New Jersey) with distinctive climates, increase of rail ridership was associated with dry, comfortable days, while the reverse was the case for moist, cool days.

In addition to the scarcity of existing research investigating the effects of weather on public transport usage, the geographic dimension of this particular issue has remained largely unexplored. We argue the need for research in this space evolves from two main reasons.

First, weather conditions such as temperature, wind, rainfall are known to be capable of forming microclimates wherein continuous variations in weather over space may be observed within a metropolitan area (Hidalgo et al., 2008; Stewart and Oke, 2012; Theeuwes et al., 2014). Given such spatial heterogeneity (and in this regard, association), weather arguably has the potential to influence both the infrastructure and the level of service to various degrees across different parts of a public transport network, hence having spatially varying influence on ridership. While not focusing on the conventional public transport modes (e.g., bus, rail), the research by Helbich et al. (2014) and Corcoran et al. (2014) partially supports this point by highlighting some discernible differences of people's use of bicycles (and public bicycle in the latter case) under weather conditions across the metropolitan areas of Greater Rotterdam and Brisbane respectively.

Second, people's travel behaviour has an intrinsic geographic component. This point has been increasingly recognised and affirmed by studies that have revealed collectively distinct patterns concerning peoples' trip-making decisions and behaviours. For example, empirical studies have found systematic variations of peoples' travel behaviours such as travel distance (Morency et al., 2011), time (Salonen and Toivonen, 2013), attitudes towards public transport (Páez, 2013), and use of transport information (Bagley and Mokhtarian, 2002; Wang and Khattak, 2011) over a city space. Factors including residential built environment (e.g., the diversity and design of a community), existing infrastructure (e.g., availability of public transport stops and services) and socio-economic conditions (e.g., income level, access to private cars) were identified as the underpinning influences. These studies have highlighted the importance of investigations at a range of spatial scales to reach a more detailed and comprehensive understanding of peoples' travel behaviour.

Taken together the spatially heterogeneous dynamics of both weather and people's trip-making behaviours will induce geographically discernible patterns of public transport ridership. We aim to empirically test this assertion through analyses of weather-ridership relationships across a range of different spatial scales: (1) system level; (2) sub-system level; and (3) visually explore route level patterns. We justify such a geographically-based methodology given its capacity to test for the existence of geographically varying weather-ridership relationships and highlight parts of the public transport network that are particularly impacted by changes in weather.