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Modelling and analysing effects of complex seasonality and weather on an area's daily transit ridership rate

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A B S T R A C T

Adverse weather is generally perceived as deterrent for public transit uses. This has also been highlighted in previous literatures. In contrary, our previous study found no association between weather and transit ridership while investigating the underlying temporal influences behind variation in daily ridership across the sub-tropical city of Brisbane, Australia. This contraindication led to the primary focus of this research. This research acknowledged that Inclusion of weather variables in conjunction with other relatively strong independent variables might result in washout of the weather effects on ridership. Variables such as rainfall do not recur on a daily basis throughout the year. Thus, generalising their effect on ridership with other independent variables that consistently influence ridership may create a similar problem. Hence, weather variables were converted into their normalised factors and combined with other independent variables while formulated the optimised the daily ridership rate estimation model. Several models were developed concerning various combinations of weather variables and through rigorous analysis it was identified that only the rain variable has noticeable effect on daily ridership. Evidently, this study functions as an update of our former study by directing towards a new approach to the analysis of the relationship between weather and transit ridership.

1. Introduction

A public transit system is a vital element of the complex urban form in a contemporary city. It is generally accepted as a sustainable and environmentally friendly means of travel. Efficient use of transit can be a key solution to reduce traffic congestion and improve the quality of urban life and its environment. Transit ridership is the single most important dimension of transit system performance and factors that influence ridership warrants utmost importance. Several elements associated with the temporal influence on ridership are responsible for its day-to-day variation within an area. Among them, weather has been prominently highlighted in previous studies.

Several studies have established the substantial effect of weather variables on transit ridership (Changnon, 1996, Guo et al., 2007, Kalkstein et al., 2009; Stover and McCormack, 2012, reference omitted for peer review, Reference omitted for peer review). Access to transit is predominantly done by walking. This implies riders being potentially exposed to adverse weather conditions. According to Guo et al. (2007), transit users are affected directly by weather while waiting or walking to and from the transit stop, and usually pedestrians are very sensitive to adverse weather conditions, which affect their comfort. Evidence from previous literature, consolidating with the general perception, dictates our notion that weather variables may influence transit ridership.

Our previous study (reference omitted for peer review), however, found no association between weather and bus transit ridership, when it investigated the underlying temporal influences behind variation in daily ridership (boardings) across a metropolitan area and formulated a daily bus transit ridership estimation model for a Western country setting. This contradiction has formed the primary focus of the research. It functions as an update of the former study by directing towards a new approach to the analysis of the relationship between weather and transit ridership, and concurrently optimising the daily ridership rate estimation model based on new research findings.

The ridership estimation model encompassed the relationship between daily bus ridership, complex seasonality factor (combines the impacts of calendar season and human activities across the year) in conjunction with day of week factor and weather variables. Daily bus ridership data for 2012 was analysed. The City of Brisbane, which is the capital of the State of Queensland, Australia was used as the case study for the previous research, with several nominated localised investigation areas (LIAs) used for more fine-grained analysis. The City of Brisbane had a resident population of 1.04 million at 2011 and has a land area of 1340.3 km^2, while the metropolitan area (statistical division) had a population of 2.1 million inhabitants.

The sub-tropical climate of Brisbane often causes sudden change in its weather condition. It is susceptible to severe weather events such

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as thunderstorms and heavy downpours, both heatwaves and cold snaps (Brisbane City Council, 2013). The city comprises of a generally sprawling land use pattern, which is typical of mid to late 20th century urban expansion, with dominating arterial roads, motorways, and tollways. Brisbane is highly reliant on its bus transit system and hosts a world-class bus rapid transit network known as 'busway', along with an extensive network of on-street bus routes. The city also has a comprehensive urban rail network and fast ferry system on the Brisbane River, although bus is the dominant transit mode. Bus is more affected by inclement weather compared to other transit modes (Guo et al., 2007). Given the dominance of bus in the city and its sub-tropical climate, it can be speculated that weather might have significant underlying influence on daily transit ridership in this region.

1.1. Research motivation

Numerous studies have identified a significant association between weather and transit ridership. For example, Guo et al. (2007) noticed a negative coefficient for rainfall across all calendar seasons in Chicago regardless of transit mode. Tang and Thakuriah (2012) also found a decreasing monthly average of weekday bus ridership with rainfall within the same region. Stover and McCormack (2012) analysed ridership in the State of Washington and concluded that rainfall is the only weather variable that exerts a significant influence during all four calendar seasons. Moreover, in Brisbane, rainfall was observed to have significant influence on daily ridership and the effect varied based on the day of week (reference omitted for peer review) or varies based on different transit user groups (reference omitted for peer review).

Similar to rainfall, other weather elements such as wind speed, temperature, and relative humidity also affect transit ridership. A recent study in Gipuzkoa, Spain (Arana et al., 2014) identified decreased transit ridership on weekends with an increase in wind speed. Likewise, Singhal et al. (2014) noticed higher negative impact on ridership at elevated stations due to wind speed. Negative effect of temperature on ridership was observed during colder weather in other studies (Cools et al., 2010; Shih and Nichols, 2011; Sabir, 2011; Tang and Thakuriah, 2012), especially when coupled with rainfall (Datla and Sharma, 2010) or snow, low visibility and heavy wind (Maze et al., 2006). This is logical, because simultaneous negative effects of any combination of factors ought to multiply the deterrent effect of temperature on ridership.

In light of the ample evidence presented in past literature regarding the influence of weather elements on ridership, we deemed it appropriate to investigate the potential influence of these variables further. This leads to the principal aspiration of this research.

1.2. Research objectives

In order to further analyse the impact of weather variables on daily transit ridership, an innovative research method was adopted. An empirical method was designed to convert the effect of each weather variables into a normalised weather factor. Since the effects of weather elements are different in different calendar seasons, their relevant factors should be calculated separately for each season. This analysis will establish whether the weather variables have some meaningful explanatory power on variation in daily ridership.

Based on the discussion above, it can be identified that the principal aim of this research is to analyse the weather variables from a new perspective and integrate the outcomes with other underlying temporal influences on daily ridership. This will streamline our previous research findings (reference omitted for peer review) and enhance the daily ridership estimation model developed in that study. To achieve the goal, this study explores the following several research questions:

- How can the weather variables be converted into their relevant factors?
- How will the weather factors affect the performance of the daily ridership estimation model?
- How is this knowledge beneficial to transport planning and research, when applied to the practical setting of the complex urban form of a metropolitan area?

Section 2 illustrates a detailed description of the research study area. Section 3 provides a background of this research based on the context of our previous analysis. Section 4 investigates the weather variables as factors. Section 5 optimises the daily ridership rate estimation model considering weather factors. This section also provides a comparison between the newly developed models with the previous model in terms of daily ridership estimation error. Lastly, Section 6 concludes the analysis and proposes future research directions.

2. Empirical study area and data

The study area and data for this research was described in (reference omitted for peer review) and is recapitulated as follows. It nominated 14 out of Brisbane's 189 suburbs to form nine LIAs. Each LIA has its unique sense of locality, belonging to an inner, middle or outer ring of the city. The suburb selection process was driven by some pre-set conditions. Areas with easily accessible urban railway stations were not included because railway stations attract transit users away from bus. Compared to bus, ferry ridership is minimal across Brisbane; hence, in the selection process some suburbs with ferry terminals were still included. The selection criteria also included land use being predominantly residential over commercial or industrial. Due to very low population densities in outer suburbs, some contiguous outer suburbs were amalgamated in the formation of LIAs to obtain a sufficiently large ridership base for analysis. Table 1 represents some demographic information regarding the selected LIAs and Fig. 1 shows their locations within the City of Brisbane.

Two types of datasets were used in our earlier study, which are daily bus ridership data and daily weather data. Both datasets were collected for a one-year period from 1 January 2012 to 31 December 2012.The daily bus ridership data for each suburb was collated directly from TransLink Division of Queensland Department of Transport and Main Roads (TransLink, 2013). Due to population difference in different suburbs, inconsistency in ridership amount between suburbs was discovered. To employ a nominal scale for unbiased comparison, each LIA's ridership was consequently converted into ridership rate (boardings per 100 population).

The daily weather data was collated from the Australian Bureau of Meteorology, Climate Data Services (Bureau of Meteorology, 2013). Three official weather stations (OWS) are located within Brisbane City, which provide quality-controlled hourly weather data, including Brisbane CBD, Archerfield Airport and Brisbane Airport. The daily weather data include four major weather variables; precipitation accumulation (mm), temperature (°C), relative humidity (%), and wind speed (km/h). Table 2 presents detail of each official weather station within the City of Brisbane, while Fig. 2 shows each station's location. Each of the weather variables was collected on an hourly basis from three stations and then converted to a daily average, maintaining a 'whole day' time frame from 06:00 to 24:00. This is because the analysis was restricted for 06:00 to 21:00 due to significantly low patronage number in late night and early morning.

The sub-tropical nature of Brisbane's climate is such that highly localized microclimates may arise. Hence for the analysis weather measurements need to be taken within each local area Each LIA is located within an acceptable distance from a single or multiple OWS. LIAs close to more than one OWS required adaptation of an 'Inverse Weight Point Average' (IWPA) method for representing weather variables for those individual LIAs. IWPA calculation method is quantified by a simple concept that out of three OWSs, if a particular station is closer to a LIA, its weather reading will better represent that area's weather condition and hence, will carry more weight. For instance, the middle category suburb, Carindale is close to two OWSs; Brisbane (7.69 km) and Archerfield