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Assessment of metro ridership fluctuation caused by weather conditions in Asian context: Using archived weather and ridership data in Nanjing

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ABSTRACT

This paper aims to assess metro ridership fluctuation caused by weather conditions in an Asian context (Nanjing, China) on metro single line and network levels. The daily ridership data utilized in the study is obtained from Nanjing Metro Agency, while meteorological data is from the Nanjing Meteorology Bureau. To address the main research questions of this paper, time-serials moving average method is extended and refined to define benchmark and to model ridership fluctuation (expressed as ridership residual). On the other hand, analyses of variance (ANOVAs) are introduced to examine meteorological events and temporal effects on ridership residuals. The data and result demonstrates that the impact of meteorological variables on daily ridership fluctuations generally results in a decrease in passengers on single lines and the travel network, especially on weekends. Precipitation related events produce more significant ridership fluctuations than temperature related events. Snowfall related events and large temperature deviations in winter account for the most dramatic changes in ridership. However, seasonality is not a significant factor in meteorological events-ridership residual relationship. This paper contributes to extending research on the weather-ridership relationship around the world especially to refining and extending the nine-term moving average method in this field. This could benefit metro operators by enabling them to add meteorological effects into their ridership prediction and budgeting work.

1. Introduction

It is commonly recognized that travel demand is the end result of a collection of individual travel behaviours, and this is a complicated relationship. So many factors influence it e.g. individual characteristics (income, gender, age, occupation, and vehicle ownership), transportation supply (transport mode options, travel time, reliability, cost, and safety), travel demand (trip purpose), temporal factors (time of a day, day of week, seasonality) and weather conditions. In recent years, more and more researchers have been paying attention to the influence of weather conditions on individual travel behaviour. Cools et al. (2010) and Murray et al. (2010) published their findings that weather conditions determined traveller's behaviours in choice of trip or not, choice of destination and transport mode, as well as route choice. They also pointed out weather had more impact on elastic trips than obligatory trips. Miranda-Moreno and Nosal (2011) concluded that bicycle usage decreases in inclement weather conditions such as cold weather and precipitation. Attaset et al. (2010), Aultman-Hall et al. (2009), and Saneinejad et al. (2012) reported weather conditions obviously affect pedestrian traffic and cyclists. Hjorthol (2013) conducts research about the relationship between winter weather and older people's mobility and pointed out that because of adverse weather conditions in winter, older people in Norway reduced their number of trips compared to summer. Creemers et al. (2015) founds weather components play a significant role in travellers' behaviours. Böcker et al. (2013) assessed the effects of climate change (average seasons) on habitual seasonal travel behaviours (transport modes and travelled distances), and demonstrated significant differences in travel behaviours between under 2050-climate conditions and present climate conditions. Meng et al. (2016) addressed cycling travel behaviours in Singapore and found that they vary in different weather conditions. During wet weather conditions, some cyclists tend to postpone or cancel their trips. Schmiedeskamp and Zhao (2016) examined bicycle ridership from a 2 year research period of automated bicycle counts at a location in Seattle, Washington in different seasonal and weather conditions by using a negative binomial model. Shaaban and Muley (2016) showed that the pedestrian volume had a log-linear relationship with the weather characteristics and the temperature was the only significant parameter affecting the pedestrian volume. According to the recent researches on weather-travel behaviour relationship, we can conclude

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that inclement weather conditions impact individual's travel behaviour by increasing the risk of travel and therefore make the travel demand fluctuate.

Similar to travel behaviour, weather conditions play an important negative role in public transit ridership fluctuation. Outwater et al. (2011) conducted an investigation in Salt Lake City, Uta about transit users' choice of mode in adverse weather conditions, and found that 12% transit riders tended to avoid transit but took an alternative mode due to unfavourable weather conditions. Arana et al. (2014) utilized daily ridership data on Saturday and Sunday in Gipuzkoa, Spain to test the impact of weather on discretionary trips and reported that transit ridership over the weekend decreased on windy and rainy days, while it increased in rising temperature conditions for both smartcard based regular riders and cash based occasional passengers. Stover and McCormack (2012) displayed adverse weather conditions such as high winds, low temperature, snow and rain which have a negative effect on transit ridership in Pierce County, Washington. Guo et al. (2007) also found temperature, rain, snow, wind and fog could make ridership fluctuate in Chicago Transit Authority in bus and rail transit systems. Cravo et al. (2009) studied the case of New York City Transit and found the magnitude of the weather's impact differed based on mode (subway, bus), day of week (weekdays and weekends) and season. Kalkstein et al. (2009) examined the effect of air masses on transit ridership in Chicago, the San Francisco Bay area and northern New Jersey. Tao et al. (2016) suggested changes in weather conditions did not significantly affect bus ridership at the system level, while some marked influence was found for rainfall, wind speed and relative humidity at a sub-system level. From the previous studies, we can draw the conclusion that weather conditions can significantly affect public transit ridership and make the number of public transit riders fluctuate.

When referring to the methodology and technology for weather-ridership relationship research, Arana et al. (2014) concluded that generally there are two ways. One is based on questionnaires for characterizing traveller individual behaviour, and the other is using passive data collected by electronic devices and management systems. In recent studies, smart card data is wildly used. From the methodology aspect, Stover and McCormack (2012) and Singhal et al. (2014) developed ordinary least square (OLS) regression. While many researches employed regression models e.g., Guo et al. (2007) with linear regression models, Cravo et al., (2009) with a cross-sectional regression model and Arana et al. (2014) with multiple linear regression model. Moreover ANOVA (Kalkstein et al., 2009), MNL-GEE models (Creemers et al., 2015) and normalised model (Kashfi et al., 2016) are also utilized in previous publications.

Following the mentioned previous works, it's a common knowledge that weather conditions can significantly affect public transit ridership in the USA, Spain, Canada, Australia, Norway, Netherland and other countries. But it's still very hard to find research about weather-public transit ridership relationship in Asian city contexts. An important issue in the transferability of findings is the fact that travel behaviour varies across spatial and temporal contexts (Khattak and DePalma, 1997). In addition, analytical results on the impact of weather parameters on travel attributes from studies in the USA, Australia, Norway, Netherland and other countries do not automatically apply to other countries, since climates and weather conditions differ highly between countries (Böcker et al., 2013). Therefore we don't know if the weather conditions impact ridership in Asia as in North America and Europe. In this case, to study the relationship between meteorological variables and public transit ridership based on the Asian context, it is essential to obtain a deeper and more comprehensive understanding of weather-public transit ridership relationship, since it can help to enrich the sparseness of research in the Asian context in this area It is also significant for transport policy makers and transit agencies in Asia to examine the potential risk and alleviate negative effects associated with adverse weather conditions.

In light of the prior results and the main adverse weather conditions in Nanjing, China, we are studying the fluctuation of metro ridership caused by meteorological variables in this paper, especially precipitation and temperature related events in different temporal dimensions. The present study is to answer how precipitation and temperature related contexts cause the metro ridership to fluctuate in Nanjing China and whether the relationship is similar as in North America and Europa. On the other hand, this paper is expected to make a methodological contribution in weather-ridership research, since it refines and extends the nine-term moving average method proposed by Kalkstein et al. (2009).

Before addressing how the meteorological variables impact metro ridership fluctuation, descriptions of the study area and ridership and meteorological data are presented in the paper. This is followed by an explanation of the methodologies adopted to identify the metro ridership fluctuation caused by meteorological variables and to assess the weather related impacts. The analysis results in Nanjing context are then demonstrated in different dimensions. This paper concludes by summarizing key findings and with a discussion of their implications for research and directions for future research.

2. Study area and data collection

2.1. Study area and time period of analysis

The study area is set to Nanjing city, which is the capital of Jiangsu province in China. 3 metro lines (line 1, line 2, and line 1 extension) have run in Nanjing urban area since June 2010. These 3 lines stretch over 64 directional kilometres through the main urban area with 55 stations. According to the annual report of public transit authority in Nanjing, the metro system shared 1/3 public transit ridership around the whole city in 2012. And ridership averaged about 1.1 million trips each day and totalled about 0.4 billion trips the whole year.

The annual precipitation averages at about 1000 mm in Nanjing (Table 1). According to Nanjing meteorological records, of the total 1197 days from January 8, 2011 through April 24, 2014, 377 days (36.6%) were observed with precipitation and 179 days (17.4%) were reported with daily precipitation > 2.6 mm (the average daily precipitation for 2011–2013) apart from public holidays.

2.2. Data collection and elimination of holiday effects

2.2.1. Background of the data collection

Considering little rain precipitation hardly impacts passengers' travel behaviours, rain-related day in this study is defined as daily rainfall precipitation ≥ 2.6 mm. However, snow precipitation < 2.6 mm is also treated as a snow-related day because snow is usually accompanied by low temperatures and will significantly affect travellers' behaviour in winter. Table 2 illustrates aggregated days with rain and snow, from which we can conclude there are 64 days in total with defined rain or snow throughout the year. Moreover, defined rain is observed mainly in summer while snow mostly in winter.

In order to obtain a reliable result, the dataset should cover sufficient information about our question without a mutation in the period analyzed. From June 2010 through June 2014 Nanjing metro network infrastructures underwent no change either at metro line or station level. Moreover, ridership was stable after an almost 6 month growth

Table 1
Aggregated precipitation from 2011 through 2013 in Nanjing.

	From 2011 through 2013	In 2011	In 2012	In 2013
Annual precipitation(mm)	2875.2	1012.0	875.2	988.0
Average daily precipitation (mm)	2.6	2.8	2.4	2.7