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Weather and cycling: Mining big data to have an in-depth understanding of the association of weather variability with cycling on an off-road trail and an on-road bike lane

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ABSTRACT

Although cycling is an easy and popular form of physical activity and urban travel, barriers exist. In particular, cycling is more likely and more severely to be affected by inclement weather than the motorized modes as the cyclists are entirely exposed to outdoor environment. Understanding the weather-cycling relationship is of great importance to academics and practitioners for cycling activity analysis and promotion. This study contributes to an in-depth understanding of how the changes in weather conditions affect cycling on an off-road trail and an on-road (bridge) bike lane at both daily and hourly scales across four seasons. The paper compares the weather-cycling relationship based on day of week and time of day combinations. The autocorrelation effect of cycling itself and the lagging effect of weather elements are also examined. The findings indicate that cycling is significantly self-dependent especially at the finer temporal scales. Weather have a very different influence on bicycle usage of off-road trails versus on-road bike lanes. When it rains its negative impact not only continues but also significantly affects the cycling within previous one hour. At the daily level, weekend cycling on the trail is less likely to be affected by weather as compared to cycling on the bike lane, whilst inverse is true for weekday cycling. Cycling is most likely to be affected by weather conditions in spring and least likely to be affected in winter. Cycling pattern which is more unrelated to weather at the aggregated level tends to be more flexibly adjusted according to the real-time weather conditions at the disaggregated level. Cyclists on weekends especially during the weekend peak hours (11 AM–4 PM) tend to have more flexibility to adjust their cycling schedule before or after the adverse weather conditions than on weekdays. In addition, cyclists with utilitarian purposes are more likely to shift from cycling to other modes (e.g., transit) due to real-time bad weather conditions in weekdays than in weekends, especially during weekday peak hours (7–9 AM and 4–6 PM). The results provide weather officials, transport agencies and research institutions with valuable information for cycling activity analysis and promotion by considering the effects of weather events especially rainfall.

1. Introduction

In urban transit management and active transport promotion, weather as a major defining factor has received increasing

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attentions (e.g., Burchfield et al., 2012; Guo et al. 2007; Liu et al., 2015a; Miranda-Moreno and Nosal, 2011; Singhal et al., 2014; Thomas et al., 2013). In particular, compared with other travel modes, cycling is more likely and more severely to be affected by weather as the cyclists are entirely exposed to outdoor environment. Although cycling has a number of social and environmental benefits and has enjoyed a continuous boom in cities throughout Europe as well as a remarkable rebirth in some North American and Chinese cities (Pucher et al., 1999; Pucher and Buehler, 2006; Zahabi et al., 2016; Zhao et al., 2014), barriers in bicycle usage and promotion still exist. Previous studies suggested that cyclists are more sensitive to adverse weather conditions than car users and transit passengers (Liu et al., 2015a; Sabir, 2011). As such it is particularly important to understand to what extent and how the changes in weather conditions affect cycling so that the potential reduction in bicycle usage due to bad weather can be ameliorated.

Indeed, a growing number of studies have sought to investigate the impacts of weather on cycling from both survey data analysis and big data mining (e.g., Burchfield et al., 2012; Creemers et al., 2015; Gebhart and Noland, 2014; Liu et al., 2015a, 2015b; Thomas et al., 2013). Findings from survey data analysis indicated that weather could significantly affect travel mode choices on cycling and other modes at the individual level, whilst big data mining exclusively focused on investigating the impacts of various bad weather conditions (e.g., low temperature, strong wind, heavy rainfall, etc.) on bicycle usage at different spatial and temporal levels. These existing studies highlighted the negative influence of inclement weather conditions on cycling and suggested academics and practitioners to address weather as a determinant in affecting cycling is worthwhile.

Although the evidence of weather impacts on cycling is accumulating and strengthening, an in-depth understanding of the relationship between weather and cycling is still one of the major challenges of our time in terms of health and green transport promotion. In particular, at least three research gaps can be identified. First, previous studies utilizing absolute values of big data to examine weather-cycling relationship did not control for the temporal variation of cycling due to non-weather effects, nor did they take into account the autoregressive effect of cycling itself (Burchfield et al., 2012; Gebhart and Noland, 2014). The inherent flaw hinders an accurate understanding of weather impacts on cycling. Second, few, if any, studies have performed time of day models to distinguish peak hours from non-peak hours. Therefore, the weather impacts on cycling with respect to different trip purposes has been rarely explored. Third, although a few studies (Miranda-Moreno and Nosal, 2011; Tao et al., 2018) have examined the lagging effect of rainfall on cycling or transit ridership, no study to our best of knowledge has examined the advance effect of weather conditions on cycling. Furthermore, a close scrutiny of the existing literature reveals that very few studies have explored cycling big data to compare the weather-cycling relationships between off-road trails and on-road bike lanes. Given that people cycling on off-road trails and on-road bike lanes tend to have different cycling characteristics and trip purposes, the influence differences of weather on cycling usage on the two typical cycling facilities are worthwhile to be examined.

This study aims to fill these research gaps and enrich the existing literature through exploring the impacts of weather on cycling on both an off-road trail and an on-road bike lane at both daily and hourly scales across four seasons. To achieve this, we have collected smart counter data for cycling on the Burke-Gilman Trail and the Fremont Bridge in Seattle, Unites States together with the detailed weather meteorological records to form an integrated database. Using an autoregressive model allied with 9-term moving average residual, dozens of regression models were estimated to examine how the weather-cycling relationships vary depending on cycling facilities, seasons, days of week, time of day, and purposes. The finer temporal data at hourly scale also allowed us to understand the advance and lagging effects of some weather events on cycling. Findings from this study will provide weather officials, transport agencies, and research institutions with valuable information for analysis of cycling behavior and promotion of cycling activity by considering the effects of weather elements especially rainfall.

The remainder of this paper is organized as follows. Section 2 provides a literature review on the relationship between weather and cycling. Section 3 introduces the study context and data source. Analytical models are presented in Section 4. Section 5 presents the analysis results and research findings. Finally, Section 6 discussed the findings and concludes the paper with potential directions for future research.

2. Literature review

Given the renaissance of cycling in recent years and the vulnerability of cyclists against inclement weather conditions, a growing number of studies have sought to investigate the weather-cycling relationship (e.g., Burchfield et al., 2012; Creemers et al., 2015; Gebhart and Noland, 2014; Liu et al., 2015a, 2015b; Thomas et al., 2013). According to the data source used for analysis, previous studies examining weather–cycling association could be categorized into two main streams. The first group of studies investigated the self-reported survey data (Creemers et al., 2015; Liu et al., 2015a, 2015b, 2016), and the second stream of studies explored naturalistic cycling data from smart counters or smart cards (Burchfield et al., 2012; Gebhart and Noland, 2014; Miranda-Moreno and Nosal, 2011; Thomas et al., 2013).

2.1. Survey data analysis

Accumulating evidence from survey data analysis indicates that weather related factors have a mild effect on individual travel behavior, and bicycle users are affected by adverse weather conditions more seriously compared to other travelers (Bergström and Magnusson, 2003; Liu et al., 2015a, 2015b; Müller et al., 2008; Sabir, 2011; Winters et al., 2007). As bicycle users are less protected against the bad weather compared to motorized travelers (Liu et al., 2015b), cyclists are more likely to reduce cycling trips due to cold or hot temperature (Ahmed et al., 2012; Richardson, 2000), rainfall (Bergström and Magnusson, 2003; Winters et al., 2007), and strong wind (Aaheim and Hauge, 2005; Flynn et al., 2012).

Previous studies indicated that cyclists' travel behavior vary significantly depending on seasons, especially the cyclists with

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