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Measuring fine-grained metro interchange time via smartphones

Weixi Gu [a,1], Kai Zhang [b,1], Zimu Zhou [c], Ming Jin [d], Yuxun Zhou [d], Xi Liu [a], Costas J. Spanos [d], Zuo-Jun (Max) Shen [f], Wei-Hua Lin [e], Lin Zhang [a,*]

[a] *Tsinghua University, Tsinghua-Berkeley Shenzhen Institute, China*
[b] *Graduate School at Shenzhen, Tsinghua University, China*
[c] *ETH Zurich, Computer Engineering and Networks Laboratory, Switzerland*
[d] *University of California at Berkeley, Department of Electrical Engineering and Computer Sciences, United States*
[e] *The University of Arizona, Department of Systems and Industrial Engineering, United States*
[f] *University of California, Department of Industrial Engineering and Operations Research, United States*

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ABSTRACT

High variability interchange times often significantly affect the reliability of metro travels. Fine-grained measurements of interchange times during metro transfers can provide valuable insights on the crowdedness of stations, usage of station facilities and efficiency of metro lines. Measuring interchange times in metro systems is challenging since agent-operated systems like automatic fare collection systems only provide coarse-grained trip information and popular localization services like GPS are often inaccessible underground. In this paper, we propose a smartphone-based interchange time measuring method from the passengers' perspective. It leverages low-power sensors embedded in modern smartphones to record ambient contextual features, and utilizes a two-tier classifier to infer interchange states during a metro trip, and further distinguishes 10 fine-grained cases during interchanges. Experimental results within 6 months across over 14 subway lines in 3 major cities demonstrate that our approach yields an overall interchange state inference F1-measurement of 91.0% and an average time error of less than 2 min at an inference interval of 20 s, and an average accuracy of 89.3% to distinguish the 10 fine-grained interchange cases. We also conducted a series of case studies using measurements collected from crowdsourced users during 3 months, which reveals findings previously unattainable without fine-grained interchange time measurements, such as portions of waiting time during interchange, interchange directions, usage of facilities (stairs/escalators/lifts), and the root causes of long interchange times.

1. Introduction

Interchange times are well-known to exhibit high variability (Zhang and Yao, 2015) and are a source of major uncertainty for the quality of services in public transportation (Aguiléra et al., 2014). Unexpected crowds at transfer stations and

* Corresponding author.
E-mail addresses: guweixigavin@gmail.com (W. Gu), zhangkai@sz.tsinghua.edu.cn (K. Zhang), zimu.zhou@tik.ee.ethz.ch (Z. Zhou), jinming@berkeley.edu (M. Jin), yxzhou@berkeley.edu (Y. Zhou), xi.liu@sz.tsinghua.edu.cn (X. Liu), spanos@berkeley.edu (C.J. Spanos), maxshen@berkeley.edu (Z.-J. Shen), whlin@email.arizona.edu (W.-H. Lin), linzhang@tsinghua.edu.cn (L. Zhang).
[1] These authors contributed equally to this work.

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excessive delays of prior transportation can easily lead to miss-connection to the next vehicle and long perceived waiting time at the stations (Fan et al., 2016). Fine-grained interchange time measurements can provide transport operators and authorities with detailed factors that may affect the traffic reliability, including congestion levels in the passages, crowdedness on platforms and usage dynamics in transit facilities such as stairs, escalators and elevators, among others, and better understand the capacities of stations (Xu et al., 2014). Such information can assist in optimizing transport timetables that minimize travel times (Sels et al., 2016; Wu et al., 2015) and improving the transit experience from a passenger's perspective (Parbo et al., 2015).

Measuring fine-grained interchange times at transfer stations is challenging, especially in metro systems. Agency-operated automatic data collection systems, *e.g.* automatic fare collection (AFC), only provide large-scale overall trip times suitable for metro network planning and evaluation (Pelletier et al., 2011). While research has been conducted to estimate several interchange times (walking, waiting and transfer) via temporal modeling using AFC data (Zhang and Yao, 2015), the prior assumptions on passenger flows and distributions might not always be valid in practice. Alternatively, extensive research has been performed to obtain direct public transit measurements from passenger smartphones through crowd-sourcing (Misra et al., 2014). GPS information from passengers and vehicles enables passenger tracking in road traffic (Bierlaire et al., 2013; Carrel et al., 2015), but it is often inaccessible in underground metro systems. Some researchers leverage cellular networks operated underground to quantify quality of service and passenger flows in metros (Aguiléra et al., 2014), but cell tower signaling alone is insufficient to support the measurement of fine-grained interchange times. The rich embedded sensors on smartphones have also attracted increasing interest in extracting trip information by sensor fusion. Various inertial sensors (Feng and Timmermans, 2013; Hemminki et al., 2013; Sankaran et al., 2014) are employed to identify transportation modes such as being stationary, walking, and riding a bus, tram, or metro and so forth. These low-cost sensors are also utilized to robustly track stops and runs of metros (Yu et al., 2014; Lee and Han, 2014; Higuchi et al., 2015; Stockx et al., 2014). However, none of the previous work has been able to provide information for fine-grained interchange times from the passengers' perspective.

The rapid development of sensors in smartphones has triggers many advanced research works (Gu, 2017; Zhou et al., 2013; Shangguan et al., 2014; Yang et al., 2014; Gu et al., 2014a). In this paper, we propose a smartphone-based approach to the measurement of fine-grained interchange time. Unlike previous works (Yu et al., 2014; Lee and Han, 2014; Higuchi et al., 2015; Thiagarajan et al., 2010; Stockx et al., 2014) that track the *Stop* and *Running* of a single metro, we focus on detecting the *Interchange* of passengers during a metro trip. Although some works (Ohashi et al., 2014; Gu et al., 2016a) have explored automatically splitting trips into walking, staying and in-vehicle states, they fail to provide detailed time information that passengers spend in passages, on platforms, or using various facilities (*e.g.* stairs, escalators, elevators) during metro interchanges. By invoking carefully selected smartphone sensors to monitor ambient magnetic fields, acceleration and cell tower signal strengths, we provide a first-of-its-kind interchange time measurement service that automatically distinguishes and measures the durations of 10 common passenger states (going up/down by an elevator/escalator/stairs, walking up/down on an escalator, walking through a passage, waiting on platforms or at the entrance of elevator/escalator) at a metro transfer station. We extract representative features from raw sensory data, which are fed into a two-tier cost-sensitive Naive Bayes classifier (Elkan, 2001) and a Conditional Random Field (CRF) (Lafferty et al., 2001).

For validation, we implemented our approach as an Android application, and conducted extensive field evaluations with 32 volunteers in 6 months, covering 14 metro lines in 3 major cities in China (Beijing, Shanghai and Shenzhen). Experimental results demonstrate an overall interchange state identification F1-measurement (Sokolova and Lapalme, 2009) of 91.0%, an average error in time of less than 2 min, an average accuracy of 89.3% in distinguishing the 10 common passenger states during interchanges. We also conducted a series of case studies using measurements from crowdsourced users during 3 months and analyzed detailed interchange times at interchange stations in the 3 major cities in China from both macro and micro points of view.

- From a macro point of view, we find that 12 out of the 34 transfer stations in our evaluation have long interchange times (over 360 s). Interchange times at most interchange stations have high variability, which increases during peak hours and decreases in off-peak hours. The portion of interchange times also varies among the multiple routes for the same origin-destination pair.
- From a micro point of view, we show that passengers can spend 50% of their interchange times waiting on the platform, which can be optimized with metro re-scheduling. A decomposition of interchange states into 10 cases reveals the passengers' behaviors, *e.g.* the transferring directions and the usage of stairs/escalators/lifts during peak and off-peak hours. Further analysis on waiting and walking times shows that the root cause of long interchange times during peak hours is mainly blockages at the entrances of stairs, escalators or lifts.

In the rest of the paper, we first discuss the literature review in Section 2, and then outline our methodology in Section 3. Sections 4 and 5 detail the technical solutions to interchange state inference and fine-grained interchange case inference. We evaluate our methods in Section 6 and present a series of case studies in Section 7. Finally we conclude the paper in Section 8.