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User-centric interdependent urban systems: Using time-of-day electricity usage data to predict morning roadway congestion

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ABSTRACT

Urban systems are interdependent as individuals' daily activities engage using those urban systems at certain time of day and locations. There may exist clear spatial and temporal correlations among usage patterns across all urban systems. This paper explores such a correlation among energy usage and roadway congestion. We propose a general framework to predict congestion starting time and congestion duration in the morning using the time-of-day electricity use data from anonymous households with no personally identifiable information. We show that using time-of-day electricity data from midnight to early morning from 322 households in the City of Austin, can make reliable prediction of congestion starting time of several highway segments, at the time as early as 2 am. This predictor significantly outperforms a time-series predictor that uses only real-time travel time data up to 6 am. We found that 8 out of the 10 typical electricity use patterns have statistically significant affects on morning congestion on highways in Austin. Some patterns have negative effects, represented by an early spike of electricity use followed by a drastic drop that could imply early departure from home. Others have positive effects, represented by a late night spike of electricity use possible implying late night activities that can lead to late morning departure from home.

1. Introduction

Central to smart cities is the complex nature of interrelationships among various urban systems. Linking all urban systems is the system users. The individual daily activities engage using those urban systems at certain time of day and locations. There may exist clear spatial and temporal correlations among usage patterns across all urban systems. A general idea is to fuse and analyze user demand data from transportation, energy, water and building systems (as shown in Fig. 1) to discover the spatio-temporal usage patterns among those systems. This enables cross-system demand prediction and management. For some users, the usage of one urban system is likely to be used minutes or hours ahead of their usage of other urban system(s) as a result of daily activity chains. Therefore, the spatio-temporal usage of a urban system can be accurately predicted a few minutes or hours ahead by real-time sensing user patterns of other urban system(s). This is otherwise hard to accomplish by solely monitoring one "siloed" system. Ultimately, real-time control strategies for demand management of one urban system can be developed with efficient real-time demand prediction upon other urban system(s).

Following this general idea, the objective of this paper is to explore spatio-temporal correlations of usage patterns between energy systems and transportation systems. Specifically, as a first attempt, we propose a methodology along with data analytics for the City

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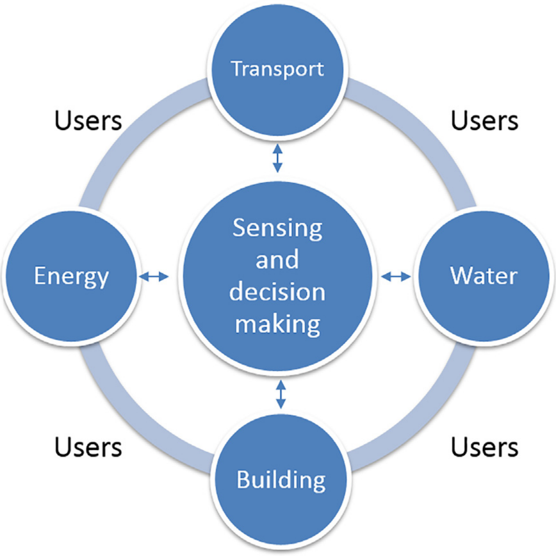
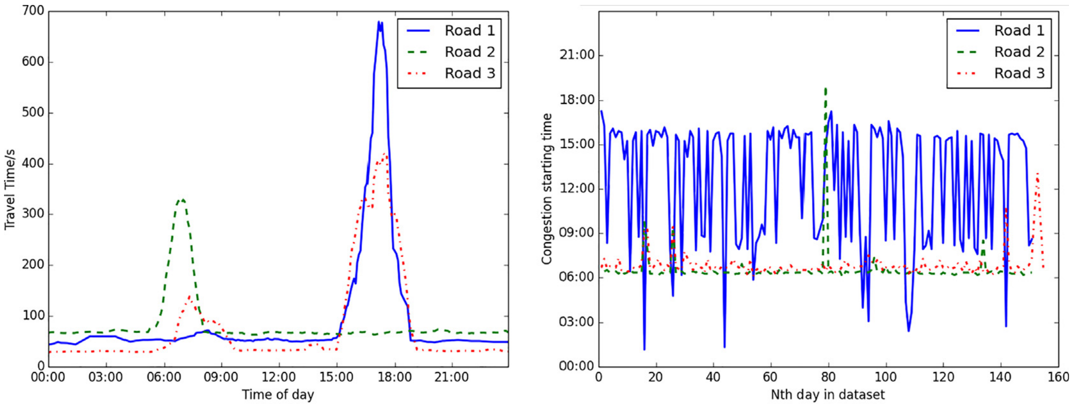


Fig. 1. Interdependency of some urban systems: their system user patterns are inter-related both temporally and spatially.

of Austin to address the following two questions. What can we tell about the morning commute by knowing households' electricity use the night before or early in the morning? How would the households' electricity use data help predict morning congestion in the real-time (or a few hours early) comparing to using real-time traffic data only?

To conceptually demonstrate why real-time traffic data is usually not sufficient for real-time traffic prediction, we obtain travel speed data for three typical highway segments on I-35 in the City of Austin. On a typical day, congestion occurs in the afternoon peak for Segment 1, but generally not in the morning. Segment 2 typically has morning peak congestion, but not in the afternoon. Segment 3 has both morning and afternoon congestion in most of days. Fig. 2(a) plots their respective time-varying travel times (in seconds) on a typical weekday (Jan 08, 2014). The free-flow traffic/passenger flow in the early morning does not exhibit clear patterns before it transitions to being congested (also known as traffic 'break-down'). For all the three segments, the travel time stays flat (namely in free flow) until traffic break-down that causes an instantaneous drop in speed. Real-time monitoring the speed or travel time does not necessarily help predict the exact time of traffic break-down, nor would historical data help as much due to day-to-day variation. If we define "congestion starting time" as the time when traffic speed reduces by 50% over 10 min, Fig. 2(b) shows the congestion starting time of those three road segments for 155 weekdays in 2014. For segment 3, the morning congestion starting time varies by 30–60 min from day to day. The day-to-day variation of morning congestion patterns on both segments 1 and 2 are less than segment 1. Morning congestion occurs for about 20% of days on segment 1. Congestion started with 6:10–6:20 am for most days on segment 2, but there are nine days when its congestion started after 6:30 am. To sum up, daily congestion patterns are difficult to predict by only monitoring real-time traffic flow because traffic break-down is very sensitive to supply/demand that is usually random on the daily basis. Historical information also does not seem to help much due to substantial day-to-day variation.



(a) (b)

Fig. 2. On weekdays, congestion varies from day to day: (a) Time-varying travel times of three road segments on a same day; (b) congestion starting time of three road segments.