Submitted to:

Call for Research Proposals: Smart City Program

FedEx Institute of Technology, University of Memphis

Project Title:

Modeling Adoption of Technological Innovations and Infrastructure Impacts in a Smart City

Area of Concentration (5): Smart Transportation Systems

PRINCIPAL INVESTIGATOR

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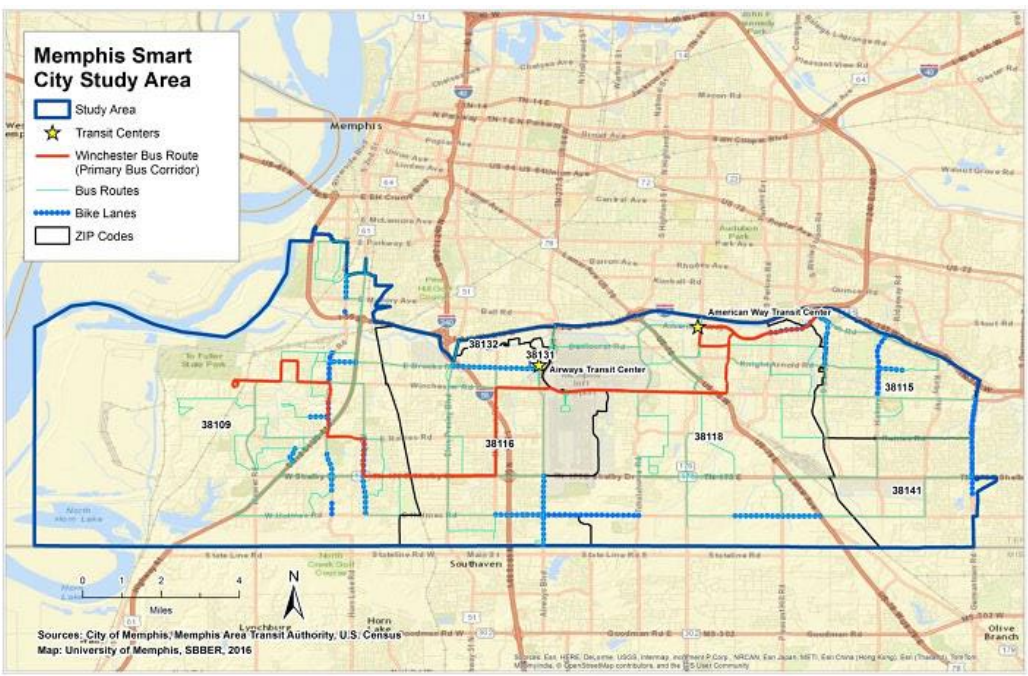

(Source: City of Memphis Smart City Proposal to USDOT)

1. Overview

The phrase “smart city” was coined in the early 1990s to illustrate how urban development was turning towards technology, innovation, and globalization [1]. Over the last two decades the phrase has been used by various technology companies (e.g., Cisco, IBM, Siemens and others) “for the application of complex information systems to integrate the operation of urban infrastructure and services such as buildings, transportation, electrical, water distribution, and public safety”[2]. Although there is no single consensus on the definition of a smart city, there is some agreement that, in a smart city, information and communication technology (ICT) facilitate improved insight into and control over various systems, including transportation among other infrastructure systems, to improve the lives of residents [3–9]. A smart transportation system constitutes an important component of a smart city given the significant portion of time citizens spend in travel. This proposal focuses on smart transportation systems with a special emphasis on changes in behavior of travelers under evolving smart transportation.

Existing methods of analyzing travel behavior do not account for a number of emerging elements of smart and connected cities. In particular, we have not yet determined **how do we determine travel behavior changes when users of innovative technologies with varying market penetrations utilize the infrastructure with traditional users?** for example, market penetration for smart vehicles is expected to grow (with some estimates showing nearly 100 percent penetration in the next 30~50 years [10, 11]) and this shift will force the evolution of intelligent transportation infrastructure in order to accommodate the needs of smart vehicles. During this evolution, a number of changes are expected to take place in terms of **technological innovation** (**smart vehicles, intelligent infrastructure, and information access**). In response to these two stimuli, the behavior of vehicle users will shift, posing challenges to traditional transportation planning models not currently equipped to handle such types of behavioral changes.

Given that current transportation planning and modeling approaches do not accommodate innovation in vehicular technology, intelligent infrastructure, and the corresponding changes in driver behavior due to real time information access from multiple sources, two research questions remain open: (i) unknown behavioral changes of users with access to evolving technologies; and (ii) lack of empirically proven descriptive behavior theory. To address these questions, the PI proposes to employ methods based on **diffusion of technological innovation** and **interactive learning** to develop theoretically robust approaches to accommodate individual travel behavior with adaptation to innovative technologies. This research will provide significant contributions to novel transportation systems complexity research based on impacts of technological innovations on transportation network planning and operations. In particular, the research consists of three tasks: Task 1: Modeling individual travel behavior to incorporate smart and connected city innovative transportation options; Task 2: Developing a platform to collect potential behavioral data from selected US smart cities and measure the adoption probabilities of innovative transportation technologies; and Task 3: Implementing the methodologies developed in tasks 1 and 2 to assess individual behavior under various travel conditions (e.g., work, shopping, leisure, recurrent and non-recurrent etc.).

The PI brings a unique background to this project that includes transportation systems planning and operations [12–14], individual travel behavior modeling [15–18], behavioral and economic studies [19–21], and organizational decision analysis [22–24]. This combination of expertise is a strong foundation for the successful completion of the proposed project. The research gaps, and theoretical, empirical, and modeling components of the proposed research tasks are described in the subsequent sections.

2. Gaps in Research and State of Practice

Individual travel behavior is well studied in traditional transportation research as a four step process: trip generation (G), destination choice (D), mode choice (M) and route choice (R) [25–28]. Research on how travelers choose their modes and routes and how travel behavior is shifting with innovative vehicular technology and near real time information access is nascent. Smart vehicle technology will follow a slow market penetration process and then emerge as the most viable type of vehicle within the next three decades. The challenge remains as how to incorporate travel behavior of a transportation system consisting of a mix of users with smart and conventional vehicles with varying degrees of information access. Yet, understanding behavior shifts in a smart and connected city context will significantly improve transportation systems planning and lead to optimal performance.

This proposal seeks to develop methodologies on transportation choice shifts considering both short- and long-term user behavioral changes in smart and connected cities. A descriptive theory of travel behavior in a smart and connected city will be developed to understand and model how travelers learn from their own experience and from other information sources, why and how they change behavior, and finally how they adapt a travel strategy. The PI proposes to develop two theories that have the potential to explain adaptation of technologies by the users (diffusion of innovations theory), and their travel behavior (interactive learning theory) after adapting to a specific technology.

3. Task 1: Individual adoption of innovative transportation options

Technological innovation and its influence is largely studied in behavioral economics, and similarities exist that are analogous to users in smart and connected cities. For example, in consumer behavior research, technological innovation study includes three types of shoppers: traditional or habitually persistent, web based purchasers, and hybrid, who use internet for knowledge, but purchase in a physical store (and vice versa). Similarly, in smart and connected cities we have users with varying information about the network conditions, hence their use of the transportation network will vary. Technological innovation and understanding of individual behavior is applied in a number of disciplines (e.g., telecommunication [29, 30], health care[31], agriculture [32], and smart phones [33]). One of the potential methods of analyzing consumer behavior, when a new technology is introduced, is diffusion of innovations theory [34, 35], which will be used in this project.

Diffusion research seeks to understand the spread of innovations by modeling the perspective of communications and consumer interactions in a network. Diffusion theory accomodates behavior of mixed categories of adopters of innovations (e.g., early adopters, late adopters, and non-adopters). In a smart city environment different communities (and different age groups within the same community) have different rates of adoption of innovations and new technologies. In addition to smart vehicles, an important characteristic of smart cities is access to real time information systems (RTIS) which can be used by network users for trip optimization (pre-trip or en-route). Historically, the benefits of RTIS for transportation are studied using inertia and compliance, with compliance dominating, especially under emergency evacuation. This study will model the rate of increase of market penetration of RTIS and smart vehicles for for the **City of Memphis** using socio-demographic characteristics and historical data for adoption using diffusion of innovation theory from similar cities (http://metrolab.heinz.cmu.edu/). The PI's first research thrust will be to study individual and neighborhood traits in the **City of Memphis** using historical data to determine the theoretical space for individual adaptation to various technologies, thus paving the way to understand how individuals have adapted to vehicular and information access technologies.

Task 1 includes theree subtasks: Subtask 1-1- Literature review; Subtask 1-2- Developing the methodology using Diffusion of Innovations Theory; Subtask 1-3- Preparing the deliverable.

Task 1 Deliverable: Technical Memorandum documenting the approach for modeling individual adaption of transportation options for the City of Memphis.

4. Task 2: Impact of innovative transportation options on travel behavior

After determining the nature of the city and how individuals respond to technological adaptation, it is imperative to determine their transportation choices. It is clear that users are not going to settle on D/M/R choices immediately, nor will they be permanently uncertain about their choices. Rather, individual transportation choices will evolve over time as users learn more about the transportation network.

Interactive learning theory assumes that individuals are self-interested and take actions to fulfill self interest. However, in a system, individuals interact and their decisions are often dependent on others' actions. Equilibrium concepts study behavior after equilibration, at the point where players have come to guess accurately what other players do. One force that produces equilibration is learning from feedback. That is, players' actions at a certain time point reflect their past experiences, which are used to anticipate future actions of others by learning. Examples of interactive learning theory include quantal-response equilibrium, cognitive hierarchy, self-tuning experience weighted attraction, and learning direction theory [36].

Learning models have been used to some degree for modeling day-to-day (DTD) dynamics of disequilibrium in transportation network [37–40], but not for modeling user behavior after the introduction of new innovations in the context of smart and connected cities. Classical interactive learning theory has been applied effectively in other fields such as pricing of product and rebates [36] and beauty contest [41] but not for modeling transportation network user behavior. Although this approach will require some transformation, similarities in the problem characteristics of interactive learning and network user behavior modeling in smart vehicles and RTIS environments suggest that the interactive learning model application is a plausible strategy. Consideration of (non)systematic sources of variability and technological advances in tracing individual movements, and the widespread intelligent infrastructure initiatives promise a rich future source of data for a better understanding of DTD dynamics using interactive learning models.

Task 2 includes three subtasks: Subtask 2-1- Literature review; Subtask 2-2- Developing the methodology using Interactive Learning Theory; and Subtask 2-3- Preparing the deliverable.

Task 2 Deliverable: Technical Memorandum documenting the approach for modeling the impact on travel behavior of introduction of innovative transportation options

5. Task 3: Implementation in the City of Memphis

The PI will collect data to understand individual travel behavior over time on use of information access and various types of smart vehicles. Some of the USDOT selected smart cities have also invited major automotive companies to test vehicles in certain parts of the transportation network before they are considered fully implementable. The PI has established collaborative relationship with number of public, and private industries to gather more data on user's response to adoption of innovative technologies in smart and connected cities, and will apply the lessons learned in other cities to City of Memphis.

Task 3 includes two subtasks: Subtask 3-1- Applying the methodologies developed in tasks 1 and 2 to the City of Memphis; and Subtask 3-2- Preparing the deliverable.

Task 3 Deliverable: Technical Memorandum documenting the results of applying Task 1 and Task 2 methodologies in the City of Memphis to provide scenario of technological adoption and infrastructure impacts.

6. Beneftits to the City of Memphis

The benefits to the project sponsors are twofold. First, the methodology of Task 1 will shed light on how individuals adopt innovative transportation options, and consequently will determine market penetration of new technologies. Market penetration estimates are important inputs for other domains investigating the impacts of innovative technologies on other issues (e.g., crime). Second, the methodology of Task 2 can be employed by researchers to understand how adoption of innovative transportation options will impact other behavioral issues (rather than travel behavior) in city of Memphis.

7. Research Schedule

Anticipated schedule of the research is shown in Figure 1.

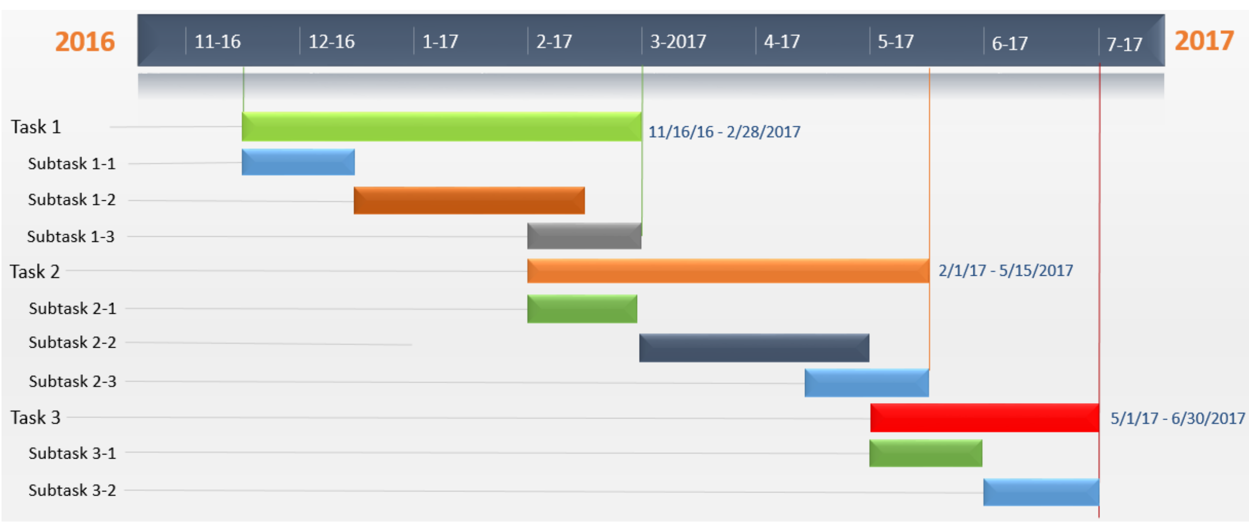

Figure 1: Anticipated schedule of the research.

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