Simulation of Web-Based Multi-Modal Transportation with Multi-Criteria Walking for Smart Cities

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***Abstract*— While current transportation simulations evaluate vehicle trips or neighborhood walkability, none can be utilized to evaluate trips that require multi-modal transportation when walking is always one mode. In this paper, we address this gap by introducing the Multi-Modal Transportation (MMT) with Multi-Criteria Walking (MMT-MCW) concept. MMT-MCW simulation can be used to evaluate various aspects of smart cities, such as walkability. The premise of MMT-MCW is based on the observations that: (a) walking can be performed for other purposes besides merely reaching destinations, such as to maintain or improve health and (b) traveler's characteristics and preferences play an important role in determining optimal route choices. Selected MMT-MCW scenarios were used to evaluate walkability of several cities with respect to three criteria: inter-modal transfer locations (parking lots and bus stops), elevation of walking routes; and walking distance. Results of simulations using these criteria are discussed and analyzed.**

Keywords-smart cities; walkability; multi-modal transportation; routing; multi-criteria walking.

I. INTRODUCTION

Multi-Modal Transportation (MMT) with Multi-Criteria Walking (MCW) is proposed as a new concept where walking is always considered as one mode and can be performed for other purposes (multi-criteria) in addition to travelling to a destination. Two sets of factors impacting MCW are environmental factors and traveler factors. Environmental factors, when compared to driving cars or riding public transportation, may have a greater impact on walking. For example, people may prefer driving cars or riding buses over walking due to rain, snow, hilly terrain, or air pollution. Location is also an environmental factor that influences walking, for instance, fastest walking routes may be based on flat and short routes which take priority over steep and longer routes. However, when walking is for exercise, the steeper and/or longer route may be preferred. Traveler factors, such as individuals' characteristics, also have an impact on choosing walking routes [15]. Several studies, such as [11], reported a correlation between individual behaviors and walking. Studies by Leslie et al. [8] and Ewing et al. [3] are examples related to the urban area evaluation in terms of neighborhood walkability. Despite the benefits of MMT-MCW for evaluating transportation options in smart cities, currently, there is no research that is focused on evaluation of city' transportation infrastructures and utilities (e.g., parking locations and walking routes).

To fill this gap, MMT-MCW simulation is proposed to evaluate three basic options: (a) inter-modal transfer locations (parking lots and bus stops); (b) elevation of walking routes; and (c) walking distance. The first option is related to MMT, and the latter two are related to MCW.

MMT-MCW may be implemented in several ways for smart cities, for example, as a new service for individuals interested in finding routes that include walking components. [6] developed a prototype service (called Route2Health) that recommends walking sessions, if feasible, for any trip. By taking origin, destination, and traveler's individual conditions as input, Route2Health recommends a sequence of transportation modes along with specific details about each mode that is most optimal (personalized). MMT-MCW can also be implemented to simulate the design and evaluation of smart cities. Existing surveys, analyses, simulations on or related to neighborhood walkability and urban design, such as [2] - [5][7][9][10][14][15], but none addresses the issues and scenarios as those possible with MMT-MCW.

The paper's contribution is a novel integration of new and existing Web techniques and technologies for evaluating and analyzing transportation options for smart cities. An information management tool (simulation) is developed to analyze mushing up data and find solutions based on existing Web services (Google Map APIs). The rest of the paper is organized as follows. Section 2 describes MMT-MCW. Sections 3 and 4 discuss MMT simulation and its results. The paper ends with a summary and suggestions for future research in Section 5.

II. MMT-MCW

MMT-MCW is concerned with finding: (a) multi-modal transportation routes with walking as one mode and finding (b) optimal walking paths by considering multiple criteria. Walking transfer node and route score are the two main factors that MMT-MCW considers in finding optimal solutions (routes).

Three modes of transportation are considered in MMT-MCW: walking, driving, and riding (bus). We define "walking transfer node" as a location where travelers switch from a pedestrian network to a vehicular network, or vice

 ISBN: 978-1-61208-407-7

versa. In MMT-MCW, walking transfer nodes play an important role in finding suitable (personalized) routes. For example, change of one parking lot to another (as a walking transfer node) may result in a different (and desired) solution. With respect to public transportation, the choice of a bus stop (as a walking transfer node) determines a specific bus route. To identify a suitable walking transfer node, traveler's desired walking distance is separated into estimated upper and lower limits. The upper limit excludes walking transfer nodes that are located beyond a traveler's maximum preferred distance. The lower limit excludes walking transfer nodes that are located closer than the desired minimum walking distance. Accordingly, one or more suitable walking transfer nodes are identified.

Route score is used to quantify suitability of a walking route in meeting traveler's criteria. To compute a route score, a relevant criterion must be identified and used to formulate its associated metric function. Examples of route score computation are based on: (1) traveler's desire to burn a desired amount of calories by walking and (2) traveler's preference for a certain level of elevation variation. Accordingly, two route scores are required: (1) calories burnt on walking and (2) elevation variation.

To calculate the calories burnt on walking, the ACSM walking equation [12] can be used:

$$EE = (0.1 \cdot S + 1.8 \cdot S \cdot G + 3.5) \cdot BM \cdot t \cdot 0.005 \qquad (1)$$

where EE is walking energy expenditure (kilocalories), S is walking speed (meters/minute), G is grade (slope) in decimal form (e.g., 0.02 for 2% grade), BM is traveller's body weight (kilograms), and t is walking time (minutes).

To calculate elevation variation, walking surface roughness is used. The walking surface roughness refers to the standard deviation of the elevations along an entire walking route. The standard deviation of a flat walking route is zero, and the higher value of walking surface roughness refers to higher variation of elevations along the walking route.

III. Simulation and Data Collection

MMT-MCW scenarios for several geographic areas (cities) in the US were simulated. The two attributes used to categorize and select the cities were population density and elevation range. Population density was simulated to explore the influence of high and low population density on walking routes and walking transfer nodes. Different elevation ranges were simulated to explore the effect of topography on walking routes and walking transfer nodes. The US Office of Management and Budget uses population density to define a statistical area. A statistical area contains one or more cities (and/or counties) and can be classified as metropolitan (high-density population) or micropolitan (low-density population). Elevation range was classified into hilly (elevation range ≥ 100 meters) and flat (elevation range ≤ 50 meters); where elevation range = max. elevation - min. elevation. The two threshold values (50 and 100 meters) were chosen for separating between hilly and flat terrains.

Two different MMTs were simulated: driving-walking and riding-walking. A driving-walking trip usually comprises (in sequence) driving, parking, and then walking, and return in the reverse sequence. Unlike the driving-walking, travellers do not have to begin with the vehicular (riding) mode in a riding-walking trip. The trip may start by walking from origin to a nearby bus stop then taking bus to destination. Walking can also be in the middle to connect two different bus routes, and the return trip can be in any sequence. For simplicity, the return trips were not considered, and walking was assumed as the mode connecting the walking transfer nodes and destinations. To this end, walking transfer nodes and walking routes were used in the simulation. The vehicular route computation between origin and walking transfer node was not considered since it is not the MMT-MCW's main contribution. Parking lots, bus stops, walking routes, sidewalk slopes, and points of interest in several cities were considered in the simulation. The data, programs, and parameters used in the simulation are described below.

The desired walking distance between walking transfer node and destination was assumed to be one kilometer. Point of interest (POI) locations were selected from OpenStreetMap [1], and 100 destinations within each city were randomly selected (in case the number of POIs in a city was less than 100, all POIs were used). To identify suitable parking lots, a buffer (inner radius: 0.5 kilometer; outer radius: 1.5 kilometer) around the destinations of interest was created. For each destination, up to 20 parking lots within a buffer were selected as suitable walking transfer nodes (note that 20 here is an arbitrary number and a suitable number may be determined for each). Bus stops and bus routes data were collected from Google Transit Feed Specification [16]. For each suitable parking lot and bus stop, up to three candidate walking routes were generated (ordered by their travel time). Parking lot locations and walking routes were retrieved from Google Place API and Google Direction API, respectively. Once all candidate routes were computed, elevation of points along the walking route of interest is retrieved from Google Elevation API, and then (1) was used to find calories burned for each candidate walking route. Walking surface roughness was also calculated using the elevations of route segments. To simulate multiple traveler's characteristics, four body weights (60, 80, 100, and 120 kilograms) and three walking speeds (60, 80, and 100 meters/minute) were used.

IV. Simulation Results

Figure 1 shows the selected cities (on X-axis), based on the criteria discussed in Section 3, the numbers of destinations and the counts of destinations that have one or more suitable parking lots (on Y-axis). The following abbreviations are used in Figure 1: Micropolitan (Mi), Metropolitan (Me), Hilly (H), and Flat (F). Most cities in metropolitan areas have a large number of destinations with suitable parking lots except Bossier and McAllen. Four cities (Barre, Kappa, Scottsbluff, and Bossier) have zero or only one destination with a suitable parking lot, which are considered outliers and excluded from the analyses.

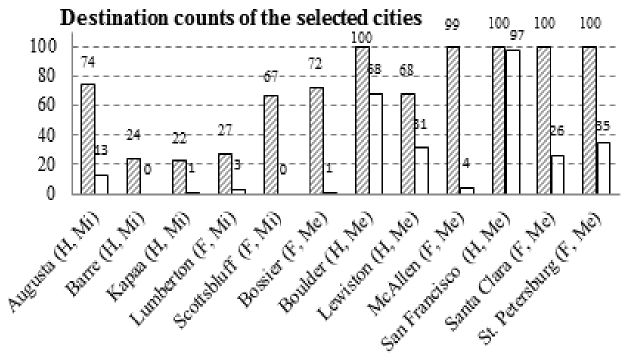

Figure 1. Number of destinations and the counts of destinations that have ≥ 1 suitable parking lots.

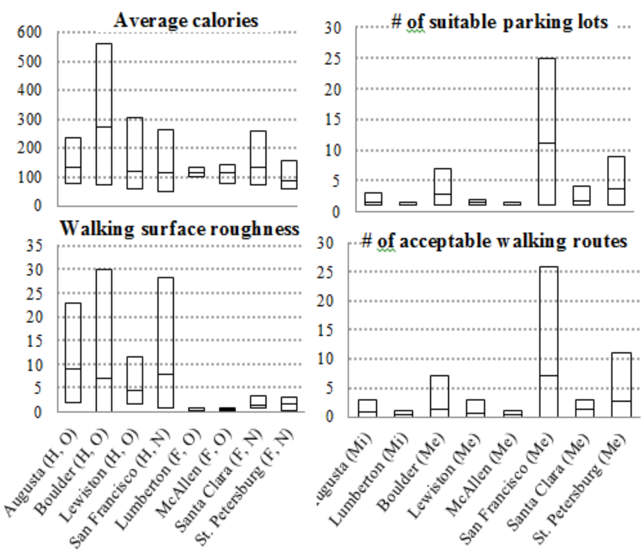

Figure 2. Comparison of attributes related to PK routes in different cities.

Figure 2 shows maximum, minimum, and average number of calories burned (top left) and walking surface roughness (lower left) for walking routes that connect to parking lots (PK routes). On X-axis, the first four cities are hilly, and the latter four are flat. The graphs indicate that hilly cities have wider ranges of both calories burnt and walking surface roughness. This is because both calories burnt and walking surface roughness are directly related to the elevation range of hilly cities and the walking routes. An interesting observation is that most cities (except Boulder) in the left figure have a similar average calories burnt regardless of the elevation range. Although Boulder has a similar walking surface roughness compared to other hilly cities, its average calories burnt is significantly higher than the others. This indicates that walking routes in Boulder are better in terms of burning calories.

Figure 2 (top right) shows the number of suitable parking lots and (lower right) shows the number of acceptable walking routes. The acceptable walking routes refer to walking routes that have their distance fall within 0.9 and 1.1 kilometer (±10% of the 1 kilometer desired walking distance). The graphs show that San Francisco has the highest average number of suitable parking lots, the highest number of acceptable walking routes, and the largest range on both attributes (largest variation of results); this is expected for a metropolitan city where transportation infrastructures are dense. Note that San Francisco is the 13th most populous city in the United States [13].

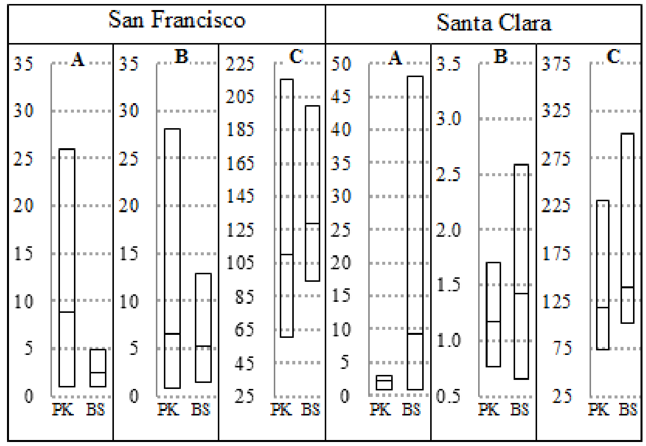

Figure 3. Comparisons between PK routes and BS routes; A: Number of acceptable walking routes; B: Walking surface roughness; C: Average calories burnt.

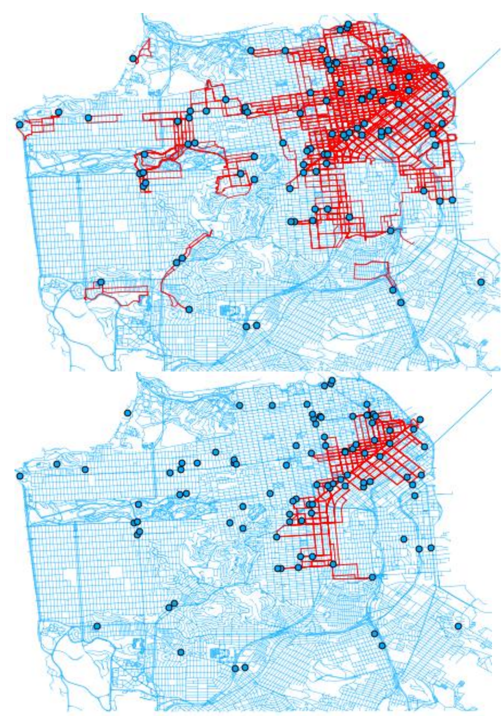

Figure 4. San Francisco: PK routes (upper) and BS routes (lower).

Figure 3 shows the comparisons between PK routes and BS routes (walking routes that connect to bus stops) in San Francisco and Santa Clara which were the only two cities (among the selected cities) that publish their transit data.

Each bar graph represents maximum, minimum, and average values. Considering the number of acceptable walking routes in San Francisco and Santa Clara, the PK routes in San Francisco have higher average value than BS routes, while the opposite behavior is revealed in Santa Clara's graphs. This indicates that PK routes and BS routes are not necessarily correlated. Considering walking surface roughness, BS routes in both cities have narrower ranges than PK routes, meaning that BS routes in both cities are more similar with respect to walking surface roughness. BS routes in both cities are also similar with respect to amount of calories burnt. PK routes in San Francisco have lower average calories than BS routes, and vice versa for Santa Clara.

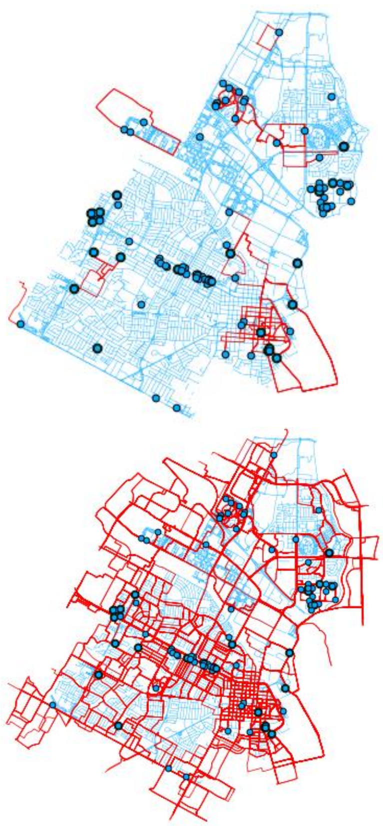

Figure 5. Santa Clara: PK routes (upper) and BS routes (lower).

Figures 4 and 5 show the spatial distribution of destinations and the coverage of PK and BS routes overlaid on the cities' road network. The maps indicate that PK routes have more coverage than BS routes in San Francisco and vice versa in Santa Clara.

V. SUMMARY AND FUTURE RESEARCH

This paper presented a new simulation approach for evaluating smart cities. Scenarios in some cities were simulated. The simulation results show that: (a) despite similar elevation range, cities may have significantly different average calories burnt for the walking routes generated and (b) two cities in metropolitan areas (San Francisco and Santa Clara) show that PK routes and BS routes are not necessarily correlated.

Considering that enhancing health and wellbeing of people, among other things, is one objective for building smart cities, our proposed approach can be used to evaluate smart cities for their environment infrastructures (roadways and sidewalks) and transportation infrastructures (different modes) and as a simulation tool to design new smart cities. Some future research directions are:

- Investigating and developing MCW optimization algorithms for travelers, such as people with disabilities (e.g., wheelchair users and people who are blind or visually impaired), people with special physical conditions (e.g., people with joint problems), and people with health conditions (e.g., people who must be less exposed to air pollution or sun light).
- Investigating and developing a predictive MMT-MCW methodology that allows route request well in advance and can monitor the recommended route up to minutes before the route is taken and update the recommendation based on changes of environmental and individual factors.
- Investigating and developing MMT-MCW simulation platforms for different purposes and applications, such as those described above.

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