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Multi-modal transportation with multi-criteria walking (MMT-MCW): Personalized route recommender

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ABSTRACT

Existing wayfinding and navigation services are designed primarily for vehicle trip planning. Of these services, currently only a few consider walking for pedestrians, and none is capable of providing multi-modal transportation with walking always as one mode. To fill the gap, multi-modal transportation with multi-criteria walking (MMT-MCW), as a personalized route recommender, such that walking is one mode and is optimized based on traveler's characteristics and criteria, is proposed. 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; (b) traveler's behavior and physical capabilities play an important role in determining optimal route choices; (c) some location parameters, such as sidewalk slope, may have much more influence on walking than on vehicular modes; and (d) environmental parameters, such as sun exposure, impact walking route choices at a specific location and time. Wayfinding and navigation services equipped with MMT-MCW will be able to provide travelers with routing options where walking is always a part of the route meeting traveler's preferences.

1. Introduction

Walking is an essential mode of transportation, and shortest distance or time is usually desired for walking routes. However, in some cases the optimization criterion is different. For example, a traveler may prefer to walk farther to a parking lot with a lower parking fee or to a bus stop with a shorter wait time, performing physical activity (by walking) while saving money and/or time. Other modes of transportation, such as driving own cars or riding public transportation, are generally preferred when distances are too far to walk. This is the reason why existing wayfinding and navigation services are primarily designed to support driving and riding modes of transportation with common requirements such as shortest distance or shortest travel time and do not consider traveler desire for walking as a primary option, especially when multiple modes of transportation are involved in planning routes.

In this paper, a methodology called multi-modal transportation with multi-criteria walking (MMT-MCW) is proposed and three research questions are addressed: (a) How should walking transfer nodes be selected for computing routes that involve multiple networks?, (b) What should be a suitable algorithm for MCW?, and (c) How can a walking route be evaluated with respect to multiple criteria?

MMT-MCW recommends routes that contain walking mode of transportation by considering multiple criteria and parameters related to traveler's behavior and physical capabilities, location, and environment. MMT-MCW can be used in two wayfinding modes: real-time mode and simulation mode. Real-time mode is used when routes are planned for immediate trips. In this mode, all candidate routes are found and one that best satisfies the environmental (such as air pollution, slope, and sun exposure) and individual (such as physical activity) criteria is recommended. Simulation mode is for evaluating routes based on scenarios that include environmental and individual criteria, preferences, and characteristics. One potential application of MMT-MCW real-time mode is Route2Health (Karimi & Socharoentum, 2014). Route2Health is a novel routing service that recommends health optimal walking sessions, if feasible, for any trip.

The proposed MMT-MCW is not addressed in the literature and introduces novel methodologies and algorithms for routing and walking options. To demonstrate the benefits of the methodologies and algorithms, an MMT-MCW simulation is implemented. The rest of this paper is organized as follows. Section 2 discusses related work. Section 3 describes MCW. Section 4 discusses the MCW algorithm in the context of MMT. MMT-MCW is evaluated using a simulation in Section 5, and its results are presented in Section 6. The paper concludes with summary and future research in Section 7.

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2. Related work

2.1. Public transit and multi-modal transportation planning

Walking is inherent in public transit as it usually requires on-foot accessible locations where travelers get on/off transit vehicles (such as bus). Walking is also used to connect between different public transits. Current public transit and MMT planning only use walking to fulfill a public transit trip, and walking is often minimized. Examples related to MMT planning are as follows. Karimi, Peachavanish, and Peng (2004) developed an Internet-based application for bus route planning with minimum number of bus-to-bus transfers. Rehrl, Bruntsch, and Mentz (2007) designed a mobile application that provides personalized multi-modal trip planning, navigation assistance for transferring between buildings, and pedestrian routes. A mobile application for urban pedestrian navigation, called NAVITIME (Arikawa, Konomi, & Ohnishi, 2007), can assist travelers with wayfinding and navigation based on MMT, including walking, driving, taxi, riding trains, busses, taxis, and airplanes. However, NAVITIME does not take MCW into account for computing routes. Li, Zhou, Zhang, and Zhang (2010) introduced a multi-modal trip planning system that incorporated real-time transit data into park-and-ride recommendations. The system uses a prediction model (based on the regression analysis and historical data) to estimate the real-time transit arrival time. Tsolkas, Passas, Xenakis, Papataxiarhis, and Tsetsos (2012) described an architecture for a personalized mobile application and a multi-modal dynamic routing algorithm which takes into account real-time traffic information and individual routing preferences.

Regarding personalized trip planning, example prior studies are as follows. Nadi and Delavar (2011) and Niaraki and Kim (2009) proposed a new approach for weighting multiple route planning criteria based on the integration of pair-wise comparison methods and quantifier-guided ordered weighted averaging. Their pair-wise comparison methods are adapted from Saaty (1980), and the quantifier-guided ordered weighted averaging was originally introduced by Yager (1988). Bielli, Boulmakoul, and Mouncif (2006) proposed a multimodal travel system using GIS routing (emphasized on mode sequence and path selection). They described how to combine transit modalities and schedules to the shortest path approaches. Pahlavani, Delavar, and Frank (2012) modified the invasive weed optimization algorithm for a personalized urban multi-criteria path optimization problem. Compared with a genetic algorithm, their method can reduce runningtime of the optimization and provide near-optimal solutions. Kolyaie, Delavar, and Malek (2008) developed a decision support system for public transit trip planning by considering individual daily scheduled itinerary.

In summary, existing MMT approaches mainly optimize the entire multi-modal trip and vehicular modes are usually given higher priority than walking mode. Unlike the existing MMT approaches, the MMT component of MMT-MCW provides options to travelers who prefer walking whenever it is possible and whose preferences are mainly concerned with walking. MMT-MCW is suitable for situations in which vehicular modes and walking mode are combined to find optimal walking routes. Although the related research supports individual preferences for walking and vehicular routing, none addresses MMT-MCW as it is defined in this paper.

2.2. Multi-criteria routing

MCW is considered as a type of multi-criteria routing. Multi-criteria routing research is focused on finding optimal transportation paths by considering multiple criteria (objectives) simultaneously. Related works on multi-criteria routing in literature are as follows. Bit, Biswal, and Alam (1992) combined fuzzy set theory and linear multi-criteria programming to address multi-objective transportation problems. Modesti and Sciomachen (1998) proposed a utility measure that takes into account the overall travel expense, travel time, and bus crowded with passengers on public transport during rush hour. The utility values from the measure are then used as costs to find the optimal path using Dijkstra's algorithm. Das, Goswami, and Alam (1999) proposed a solution to multi-objective transportation problems by expressing objective functions as interval degradation allowance values and then applying a fuzzy programming technique. Li and Kurt (2000) introduced a multi-objective linear programming model for transit itinerary planning and used it in a two-phase heuristic algorithm. Claus and Martin (2004) integrate multi-criteria evaluation with LBS to provide personalized decision support for three user groups: business traveler, tourist, and low-budget tourist. Yu and Chang (2009) propose a system architecture and design methods for location-based recommendation for mobile platforms. Katagiri, Uno, Kato, Tsuda, and Tsubaki (2013) use multi-objective programming to solve the tour route planning problem in which the number of constraints is a polynomial order of the number of places possible to visit or stay. Pahlavani and Delavar (2014) use a neuro-fuzzy based methodology to learn driver's preferences and perform multi-criteria driving route planning. Despite these previous works, there is a void in literature addressing MCW as it is defined in this paper. For example, none of the previous works discuss walking criteria and how they should be selected, and there is also no detailed evaluation of multi-criteria walking routes. Furthermore, they also do not consider selection of locations where travelers switch between walking and vehicular modes with respect to personal preferences and criteria.

3. Multi-criteria walking (MCW)

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 busses over walking due to rain, snow, or air pollution. Location also influences walking, for instance, finding fastest walking routes requires flat and short routes which take priority over steep and long routes. However, when walking is for physical activity, the steeper and/or longer route may be preferred. Also, people's characteristics and preferences have an impact on choosing walking routes. For example, obese adults tend to walk slower than adults of healthier weights (Malatesta et al., 2009). People's step lengths tend to decrease as the declination angle of the walkway surface increases (Sun, Walters, Svensson, & Lloyd, 1996). Himann, Cunningham, Rechnitzer, and Paterson (1988) have also reported a negative relationship between age and speed of walking. Currently only a few wayfinding and navigation services support walking for pedestrians, and none is capable of providing multi-modal transportation with multi-criteria walking as one mode. To fill this void, a routing methodology to provide multi-criteria walking in the context of multi-modal transportation is required.

MCW refers to the walking component of a route determined by MMT which is optimal by taking into account multiple criteria simultaneously. Example criteria are distance, difficulty (such as steepness), safety, weather condition, air pollution, and health benefits. The context-aware walking segment technique and walking transfer nodes selection technique are included in the MCW component of MMT-MCW and described below.

3.1. Context-aware walking segment

MCW optimization involves various criteria for evaluation of walking routes. Examples of criteria are shortest travel distance, shortest travel time, specified level of calories to burn, minimum traffic related air pollution exposure, and minimum slope variation. For each criterion, a relevant attribute will have to be identified, for instance, elevation is the relevant attribute for minimum slope variation criterion. Associated with a walking route, Fig. 1 illustrates four example attributes: sun exposure, air pollution, elevation, and distance. The criteria related to these four attributes can be minimum sun exposure, minimum air pollution exposure, minimum slope variation, and shortest distance. The origin and destination of the walking route is represented by a circle and a square shape, respectively. The turning points (diamond shape)