Towards Health-Optimal Routing in Urban Areas

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ABSTRACT
People are continuously on the move in their daily lives for various purposes ranging from trips to work, to leisure facilities, or trips being recreational by intention. Finding an optimal route for each trip and purpose which corresponds to their preferences is often difficult. People frequently consult route planning services which offer them to choose between the calculation of the fastest or most direct route, and sometimes even the most scenic route. As soon as several transportation modes are involved, the range of routing planners taking into account multiple modes of transportation is either strictly limited or no such service at all is available.

In this position paper we outline a proposal for making mobility in urban areas healthier. The healthification of urban mobility will be supported by a health-atlas platform. The core of this platform will be a routing service that incorporates all available and possible modes of transportation, and proposes to its users the healthiest path between an origin and a destination. Determining such route will take into account individual preferences and personal mobility restrictions; it will also be based on the involved level of physical activity and exposure to polluted air along the route which often varies for different modes of transportation. Information about air pollution will not only be obtained from official measuring stations but also by the users themselves, through geo-referenced air quality measurements with their mobile devices. These data will then be made available through the health-atlas in a crowd-sensing manner and thus provides a real-time air pollution snapshot.

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General Terms
Design, Experimentation, Human Factors, Management, Measurement, Theory.

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1. INTRODUCTION

1.1 Urbanization and Air Pollution
Nowadays, more and more people live in urban areas. The UN calculated for the time period between 1950 and 2011 an average yearly growing rate of the world urban population of 2.6 %. It is assumed that this trend will continue until 2030, however, with a slightly smaller annual growth rate of the world's urban population of 1.7 % [16].

Associated with the higher density of people living in urban areas there is also a higher traffic density compared to rural areas. In urban areas a large share of vehicular traffic is especially problematic since it is considered a major source of air pollution. The higher density of vehicular traffic and people being affected in urban areas pronounces the negative impacts of polluted air on human health, ranging from difficulty in breathing and nausea up to lung inflammation and increased mortality [10]. Whilst the relatively coarse-meshed network of governmental air quality measuring stations can be used to provide an overview of the air quality at a regional level, air-quality data at an urban street level come with significant local variations since the distribution of pollutants is restricted by obstacles such as buildings. Therefore it is almost impossible to make any statement about the level of air pollution the urban travelers are effectively exposed to. Polluted air is a major source for health costs. A study, commissioned by the city of Zürich, Switzerland, estimated the traffic induced air pollution at around $200M [9].

Mobile air-quality sensing has been a topic in several research projects, for example, using smartphone cameras [2] or small stationary sensors [1]. Incorporating geo-tagged measurements from citizens refers to the area of volunteered geographic information [6].

1.2 Physical Activity
As stated by [5] in recent decades much of the physical activity has been eliminated from people's daily lives. A deficiency of physical activity is, besides insufficient nutrition, one of the main reasons for the increasing number of people with obesity. The *World Health Organization* considers this a global epidemic [19]. Besides reducing the risk of being affected by overweight, an increased level of physical activity decreases the likelihood of being affected by cardiovascular diseases, diabetes mellitus type 2, as well as anxiety and depression with the corresponding positive implications, lowering the overall costs for the public health system [4, 7, 15].

1.3 Health Aspects of Multimodality

Especially in urban areas, for the satisfaction of the urban dwellers' mobility needs, a wide range of possibilities is available ranging from private cars to public transport and human powered mobility modes, e.g., walking or cycling. These transportation modes differ on the one hand regarding the traveler's exposure to polluted air and her degree of freedom to influence such exposure [4, 8].

On the other hand the mobility modes are different regarding the traveler's involved level of physical activity. Human powered transportation modes in particular provide a viable opportunity to incorporate a higher level of physical activity within daily mobility. They are also best suited for short trips which are especially predominant in cities.

Common route planners such as *GoogleMaps* offer routing services for individual transportation modes but do not support the calculation of trip possibilities combining multiple modes. Furthermore, as routing options only "fastest" or "shortest" route are commonly offered. Possibilities to determine the healthiest way to get from A to B are so far limited to pedestrian navigation tools. In [17], for example, a navigation tool for selected cities in the U.K. is presented, where pedestrians can choose between the routing options "direct", "less busy" and "low pollution". Sharker et al. [14] investigated a method for weighting pedestrian path segments of a navigation service in order to compute health-optimal routes. The proposed weighting computation takes into account environmental factors, such as walkability or segment length, as well as individual factors, such as time constraints or amount of calories intended to be burned.

1.4 Spatial Exposomes

In recent years mobile devices such as smartphones equipped with a variety of sensors and capable of determining their current location have become ubiquitous and opened up a wide range of new possibilities in the fields of self-monitoring, crowd- and participatory sensing. With small external sensors, pluggable to these devices, the range of sensing and monitoring opportunities has become even larger [11, 20].

Referring to the genome which recognizes the failure of genes in order to explain significant differences in the occurrence of human diseases, Wild [18] in 2005 introduced the term *exposome,* now widely used in health research [3]. The exposome describes the total amount of potentially health-impairing agents a person comes into contact with over the course of her lifetime and also takes into account behavioral factors such as the level of physical activity. The mentioned trend of self-monitoring and participatory sensing with geo-enabled mobile devices pushes exposome studies to the next level, letting people discover their own exposome based on their spatio-temporal behavior [3].

2. HEALTH ATLAS

In this position paper we outline our idea of combining the concepts of mobile- and participatory sensing, exposome studies, multimodal trip planning and healthy-routing towards a *health-atlas* which enables the calculation of personalized health-optimal multi-modal routes and motivates its users to engage in healthier urban mobility. The health-atlas is intended to be available for urban areas and we are planning first tests in the city of Zürich, Switzerland. The definition problem of how a health-optimal multi-modal route is defined will be briefly discussed in the third section of this position paper.

2.1 Main Components

2.1.1 Service & Base Data

The health-atlas is planned as an online service accessible by common web-browsers or a mobile-phone application. Recommendations for healthy multi-modal trips will be given in real-time based on an underlying public transit timetable and extensive street network data incorporating pedestrian- and cycling-paths. In addition, healthy multi-modal trips will be recommended based on static datasets providing a coarse overview of the spatial distribution of air- as well as noise-pollution. A more realistic image of the spatio-temporal air- and noise-pollution patterns can be achieved through the application of appropriate models on static datasets, taking, for example, into account time of day or weather conditions but also by integrating air-quality and noise pollution data sensed by health-atlas users with mobile devices or by instruments placed on public transit vehicles [13]. The major advantage of mobile sensed data resides in their high spatio-temporal resolution, their usability for assessing the exposure levels of individuals and their currency providing a real-time air pollution snapshot.

2.1.2 User Profile

The health-optimal trip recommendations will not only be based on generic data but will also consider personal information stored in a user profile. This user profile enables to define individual boundary conditions ranging from mobility possibilities and constraints to the state of health as, for example, suffering from respiratory diseases.

2.1.3 Mobility Profile

In the context of the health-atlas mobile devices are not only used to contribute data. They also enable the tracking of a user's mobility history including information about which transportation modes one has used (automatically derived from GPS- and accelerometer data) as well as to which pollution levels one was exposed to (e.g., based on external air quality sensors). Consequently it will be possible to create a personalized "how healthy is your daily mobility"-profile which reflects a part of a person's total exposome. In cases where the user is not equipped with appropriate hardware to sense her pollution exposure directly, the exposure could be determined approximately through the health-atlas based on the GPS-track and static pollution data stored there as similarly proposed by [12].

2.2 Operational Aspects

The proposed health-atlas can be used in two different manners.

First, it can be used in a passive way, which means that a person installs the health-atlas mobile application on her smartphone and lets her trips being tracked in order to automatically create the personal mobility profile. This provides the user with an overview of her mobility behavior. Being more aware of one's behavior can lead to critically rethinking habituated behavioral mobility patterns. In the passive mode, the health-atlas mobile application can also be used to pose warnings to the users based on their user profile and current location, e.g., cautioning an asthmatic sufferer when she enters an area with high air pollution levels.

The second manner of using the health-atlas is in an active way. Users being able to sense air quality and noise pollution with mobile devices can share these data through the health-atlas platform with other users, thus providing a more complete picture of local air pollution variations. Enabling, for example, asthmatic sufferers to share locations with the health-atlas community where they had an attack, makes it possible to derive crowd-sensed asthma risk maps. Furthermore, users can determine health-optimal trip recommendations for various trip purposes and with respect to personal limitations and preferences.

Based on the mobility profile the health-atlas can be used to organize competitions among users for the most relevant mobility profile changes towards a healthier mobility behavior (similar to location-based games). The users can be motivated to participate in such contests through incentives for having the most relevant mobility profile changes within a certain period.

The mobility profiles could also be used in the context of health insurance fees. Insurance companies could set a goal with their clients towards a healthier mobility behavior. If a policy holder reaches her goal she can earn a health insurance premium discount. If the user's profile reveals a tendency towards an unhealthier mobility behavior she can be penalized with an increased health insurance premium (similar to car insurance vehicle tracking).

Figure 1 provides a coarse overview of the health-atlas system.

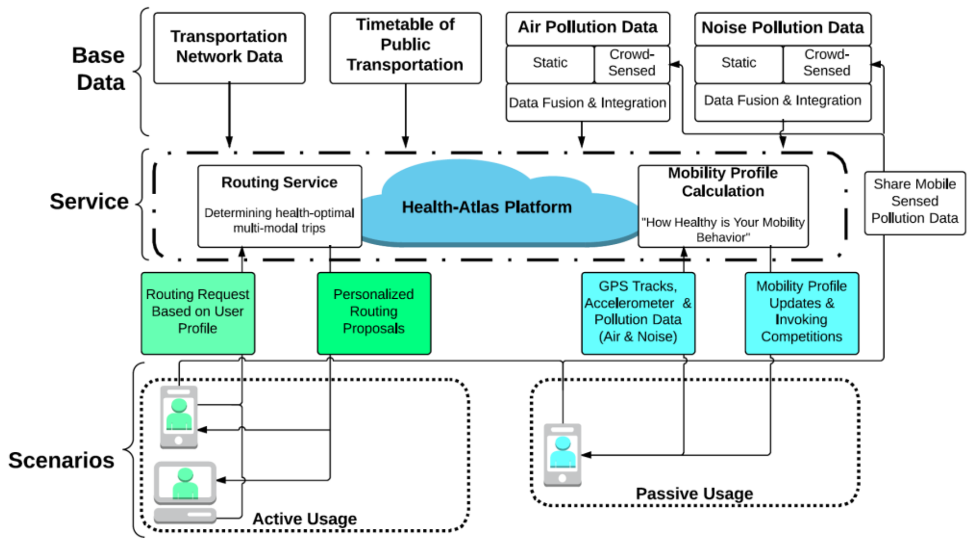

Figure 1. Coarse overview of the *health-atlas* system

3. HEALTHIER MULTIMODALITY

3.1 External and Internal Factors

The health-atlas as described in the previous section enables the determination of the healthiest route to get from point A to point B in an urban area taking into account all available modes of transportation. However, what is perceived to be healthy and what is effectively healthy highly depends on an individual's perception as well as factors such as a person's age or whether the person suffers from chronic or respiratory diseases. Following [14] we propose also for multi-modal health routing two different categories of factors for determining a health-optimal multi-modal trip, called "external" and "internal" factors. "External" factors are considered to be the same for all individuals, e.g., air pollution along a specific walking route from A to B or weather conditions. "Internal" factors depend on individual preferences and requirements such as personal mobility restrictions, available time budget, allergies or a variety of soft-factors like time pressure.

3.2 Empirical Studies

In order to gain an insight into the significance of health aspects in urban mobility and to shed light on which factors are considered by people evaluating the healthiness of a trip, we intend to follow different viable questionnaire-based approaches. As a first step we plan to ask participants to respond to open questions such as "what is generally seen as healthy mobility?", "what are healthy aspects of selected transportation modes?" or "which factors are considered if one has to plan the healthiest trip to get from point A to point B?" Based on the results of the first step one could let the participants rank factors relative to each other which are possibly relevant for determining a health-optimal trip. This could provide a first impression of the relative weighting of the factors. As a next step a stated preference survey is foreseen. It may provide deeper knowledge of people's trade-offs planning multi-modal health-optimal trips. On the one hand trade-offs between different factors defining a health-optimal trip and on the other hand trade-offs among travel time, trip costs and healthiness of a specific trip can be analyzed in this way.

The above outlined questionnaire-based empirical studies could also be used to determine differences regarding factors being considered for a healthy trip between various demographic groups (e.g., retired people versus working population or asthmatics versus people without respiratory diseases) as well as for different purposes (e.g., commuting trips versus leisure trips).

4. CHALLENGES & FUTURE WORK

Privacy concerns of health-atlas users are expected and need to be addressed properly. On the one hand it is necessary to assess how comfortable users feel in general having their mobility activities recorded and evaluated. In the context of recent debates about data security in the world-wide-web users might be especially concerned sending GPS tracks to the health-atlas platform sharing mobile-sensed air quality measurements or determining air pollution exposure based on air pollution data stored on the health-atlas platform.

The amount of air pollutants inhaled by a person does not only depend on the ambient air quality but also on the respiration rate. A combination of pulse rate measurements together with tracking data could be used to estimate the volume of inhaled air while being on the move and thus providing a more realistic picture of an individual's air pollution exposure.

Further challenges arise regarding the mobile sensed air quality data. Methods need to be developed to allow the combination of air quality measurements from various mobile devices with measurements from official measurement stations. It will also be necessary to ensure the consistency and reliability of the mobile-sensed measurements.

Providing any sort of incentives for mobility profile changes towards a healthier behavior might be susceptible to fraud. In order to benefit from an incentive, people could lend their smartphones to people with a healthier mobility behavior and let them participate in the incentive. Investigations are necessary whether and to what extent such fraud could be detected automatically. From an equality and ethical point of view, health insurance premium based incentives are particularly delicate because some people do not have any possibilities to adapt their mobility behavior as, for example, disabled people. Therefore they would be excluded by default from obtaining health insurance premium discounts.

Furthermore, it would be interesting to develop a benchmarking system that enables to measure benefits of using the health-atlas platform. At an individual level, such a system allows to determine which efforts and adaptions of the daily mobility behavior need to be made by people with different backgrounds in order to achieve the same health benefits. For example, this would allow for the identification of user groups with a large potential of making their mobility behavior healthier with comparably small efforts. Determining the health-atlas benefits for the health system in general could be used as a basis to disseminate incentives among health-atlas users. Saved health costs could be forwarded to health-atlas users based on mobility profile changes in the form of health insurance premium discounts.

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