A Big Data Approach to Developing a Smart Pedestrian Network (SPN) System

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Abstract: - In an era of digitalization, artificial intelligence, Internet of Things and Big Data great opportunities arise for effectively directing urban development towards sustainability. Big Data solutions provide the structure for new relationships among organisations with the possibility of developing a variety of innovative products and services that satisfy peoples' needs but also consider the environment. For successful development of innovative products it is necessary to implement digital solutions involving a variety of data sources. Factors to consider revolve around the choice of platform strategy, which should handle aspects such as the provision of Application Programming Interfaces (API), how open the access to data should be, privacy and security concerns. This paper examines design issues for developing a digital ecosystem for sustainable urban mobility. The main focus is to suggest solutions for the deployment of a Smart Pedestrian Network (SPN) system. The proposed solution combines multiple subsystems, such as Geographical Information Systems, intelligent agents, sensor systems, crowdsourcing, and social networks to create an integrated big data system of the urban environment. Such a big data approach would be very useful for facilitating the cooperation and co-creation among business, governmental organizations and people.

Key-Words: Sustainable Development, Urban Planning, Sustainable Mobility, Big Data, Platform Strategies, Innovation, Municipality, Smart City, Intelligent Systems,

1 Introduction

Big Data creates a unique opportunity for solving many urban sustainable development issues and especially realizing the vision of the so called smart city. At the same time, big data applications present great challenges to be successfully implemented. Especially in the case of urban development, there are numerous aspects that need to be taken into consideration such as platform strategies, multi sided markets (MSM) and network effects.

The importance of Big Data for urban development is highlighted by Rabari and Storper [1]. It is suggested that the urban environment of today's cities is a sea of sensors and meters, that calls for exploitation. Further, the urban environment is a platform for generating data on the activity of human society and human interactions that revolutionizes our economic, political and social processes.

This paper investigates the use of big data for promoting an ecosystem of urban development for sustainable active mobility. This is achieved by effectively collecting data about the city pedestrian network and provide relevant appropriate mobility information to people. As a result, a framework for a viable smart pedestrian network ecosystem is proposed for promoting active transportation, which contributes to a higher quality of life as it is beneficial both to people and the natural environment. The proposed pedestrian network ecosystem aims at revolutionizing our way of living and create conditions of industry innovation in the transportation sector.

The next session goes through a literature review on big data applications as well as the latest methods of collecting mobility related data in an urban context. This followed by the Proposed Big Data Urban Environment framework and its application in the case of developing a Smart Pedestrian Network (SPN) system. Finally conclusions are drawn and recommendations for successful implementation are provided.

2 Literature Review

Recently, numerous studies have been carried out on the use of Big Data for enhancing the quality of service municipal organizations provide to their citizens and promote sustainable active mobility. Some of the most important studies are presented in this section, where significant components for a successful big data implementation are revealed.

In a recent work [2], automatic detection of accessibility issues in a city was explored. A system was successfully designed and tested for collecting data from RFID/Bluetooth devices and smartphones for providing useful information to disabled people in order to improve their mobility. The system differentiates between routes with impediments and routes that are suitable for disabled people. The success of this system is very much relied on motivated active participants. Also, in implementing this big data system, a key factor was the fact that it does not hold private information. The collected data, which is further analysed, is presented in a meaningful way to participants as well as to municipal organizations in order to identify issues regarding the urban environment and take appropriate action.

As Social Networks provide a rich source for big data applications, the introduction of a Social Networks component in Cyber–Physical Systems is evaluated [3]. This integration results in what the authors call Cyber–Physical–Social Systems (CPSS), combining the observations received through the “Internet of Things” sensor devices, where citizens provide context via social networks. The resulting fusion of data provides a better understanding of the real world, enabling new services for citizens. However, the CPSS has much greater requirements in the form of Big Data, and this paper reviews various solutions for the issues presented. Such requirements are, data manipulation, identification and verification of data sources, and processing and fusion of different types and scales of data. In another study [4], trust is revealed to be a major issue when collecting and disseminating big data on a city scale. A reputation system architecture was designed, whereby trust is built on feedback from both citizens and other nodes where a portion of trust is accumulated when offering reliable information.

In a gamification/crowdsourcing-oriented study [5] the visualization of pedestrian generated data was proposed by combining cartography and walkability rules. A gamification process was utilised that was proven it infuses a shared responsibility about the quality of data collection. Here again, we see the significance of providing incentives for the participation of citizens in data collection.

In a case study on analysing telecommunications big data for urban transport [6], it was successfully managed to track tourist movement and traffic. In this way significant information was collected about route choice preferences of tourists without violating data privacy or compromising data quality. Such a big data implementation would be very beneficial for municipal organizations of tourist destination cities, to evaluate the attractiveness of their main sights. Also, the issue of privacy is of major importance when it comes to collecting data from people in a city. Joy et al. (2016) [7] proposed a scalable smart city privacy preserving architecture that enables the divulgement of local privatized data. This is achieved by privatizing data on the source device.

A data-driven methodology [8] towards studying the dynamics of a city shows the structure and the character of a city on a large scale. Geospatial social media data is utilised and a model is devised that detects activity patterns of people in a city. The model follows a clustering approach that maps a city based on the collective behaviours of its citizens. An interesting result was that the flow of people through the streets of a certain area is shaped by the geography and the architecture of the place.

Core problems and challenges in the area of urban computing [9] are identified and a general framework for digitizing the urban environment is proposed. The framework consists of four interconnected layers, urban sensing, urban data management, data analytics, and service providing. The focus however is on data generated by motorized vehicles i.e. car mobility data, environmental sensors and social media data which focus on car mobility.

Unfortunately most work on Intelligent Transportation Systems (ITS) promotes vehicle traffic instead of sustainable mobility [10]. A lot can be done for the environment should we invest in developing intelligent systems for active sustainable mobility.

Clearly, pedestrian mobility data is very much ignored in urban computing. However, several specific methods on collecting data about pedestrian mobility have been developed and are presented in the next subsection.

2.1 Collecting Data on Pedestrian Mobility

As pointed out earlier pedestrian mobility is rather ignored as most Intelligent Transportation Systems (ITS) applications promote motorized traffic flow. There is though a thread of research on collecting data on pedestrian mobility. For example, Bolten *et al.*[11] developed a customizable routing solution for pedestrians with disabilities based on a pedestrian-centric trip planning solution/a web map. This solution takes into account permanent barriers that pedestrians can face, like diverse sidewalk surface types, evenness of terrain, stairs, curbs, elevation changes, steep inclines as well as transient conditions like weather and construction works. The model accommodates many user groups needs in an open, shared spatio-temporal network. This enables people with different abilities to move independently in the streets and make use of all services employing current and relevant routing information.

Collecting pedestrian geodata via peoples' smartphones could be of great importance. Smartphones nowadays have embedded GPS, magnetometer, gyroscope, and accelerometer. Integrating the data from such sensors is very important for effective urban planning. A series of images for example in combination with GPS can be used to reconstruct 3D models making it possible to develop a map of the built environment.

Moreover, in order to generate a building environment map machine learning techniques can be applied on crowdsourced information. Classification techniques such as Euclidean distance, logistic regression, support vector machines, decision trees, naive Bayesian classifiers and cross validation can be further used. By enabling such techniques crowdsourced learning could be a possible method for addressing pedestrian data problems.

In another study Jwa *et al.* [12] created pedestrian networks and attributes of node, link, and points of interest to develop a smart tour guide based on a mobile pedestrian navigation system. A combination of 2D based maps and sky view maps in urban areas was utilised in an urban area. The pedestrian network model was created using on-site GPS trajectories matched with photos.

In order to support the trend for the development of healthy communities by improving the pedestrian environment and make the cities more walkable Cheng *et al.* [13] developed an image-based machine learning method for detecting pedestrian activity from Google Street View images. Google Street View provides panoramic views along many streets around the world. The detection results of this method are encouraging since they are similar with the pedestrian counts that are collected by field studies.

Further, Din *et al.* [14] focuses on enhancing feature extraction techniques in order to be able to detect and classify correctly data that have been received from pedestrian areas that are affected by different factors such as lighting, object collisions, backgrounds, clothes, and occlusions. Some features that can be used for pedestrian detection are histogram of gradients, scale-invariant feature transform, Haar built, occlusion feature extraction, support vector machines and random forests. These features extraction and pedestrian detection methods are used by convolutional neural networks (CNNs). The CNN-based approach provides more accurate results when larger data sets are used.

Furthermore, Yin *et al.* [15] developed an image detection method that determines with sufficient accuracy the presence of pedestrians in specific areas. The data that were used to train the algorithm were collected from over 200 street segments in Buffalo, NY, Washington, D.C., and Boston, MA. For image detection the research team downloaded and assembled images taken from Google Street View images. These data were analysed for extracting pedestrian count data utilising machine vision and learning technology.

As shown above new technology and methods are available that makes it possible to collect a variety of data related to pedestrian mobility. Further, it is proven that Big Data projects are necessary especially in developing solutions for sustainable urban development. On the other hand, successful implementation of Big Data projects is quite challenging and depends on a variety of factors. These include the motivation of participants, data quality, citizens' privacy, integration capability, connectivity, trust and a good spirit of community among the various stakeholders. It is also important to note that little has been done to facilitate pedestrian mobility as compared to motorised vehicle traffic. The proposed methodology for developing a pedestrian big data ecosystem takes into account these issues and is presented in the next section.

3 The Proposed Big Data Urban Environment Framework

As we have seen in the literature review, big data provides enormous opportunities for sustainable urban development. Through Big Data applications municipal authorities can increase the quality of service they provide to their citizens as well as other market segments such as tourists [16] and visitors. We envision a digital ecosystem having intelligent functionality, integrating a variety of internal and external data sources [17] as depicted in Fig. 1.

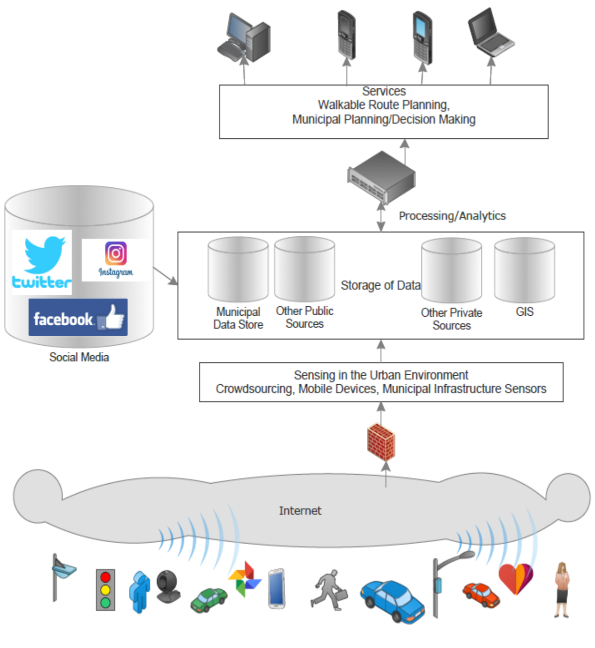

Figure 1: The Proposed Big Data Urban Environment Ecosystem (Papageorgiou *et al.* [17])

The proposed big data system follows the general approach of [9], but also includes the needs of the pedestrian network. This is carried out by incorporating the idea of Intelligent Pedestrian Mobility Systems (IPMS) [18] and peoples' attitudes on the quality of service of the pedestrian network [19]. Further, aspects of planning for sustainable urban development [20] should be included. Moreover, learning and diffusion [21] within the context of urban development and sustainable active mobility should be considered.

Aiming at improving the conditions of the urban environment, with metrics such as connectivity, comfort and convenience, the proposed ecosystem collects data from all the relevant stakeholders. Data is then analysed by the municipal organization and action is taken accordingly. On managing and running the system, care should be taken on the interface design functionality based on user needs, data quality as well as privacy and security issues.

The proposed system should be available on multiple platforms such as personal computers, smartphones and smartwatches to provide information for safe and comfortable mobility, serving the needs of multiple markets, such as commuters, tourists, disabled people, schoolchildren, and others.

The various user groups would also feed information to the system through crowdsourcing and social networks, so that the municipal organization would assist in assessing the urban environment conditions in an almost real–time manner. Connectivity is a central theme of the envisioned system, incorporating multi–modal mobility options such as public transport, carpooling and autonomous vehicles. The process of collecting data is automated by fusing sensor network feeds, geographical information systems (GIS), municipal legacy systems, open data sources, machine learning processing of social network platforms such as twitter, Instagram, and Facebook. In this way, municipalities and other local authorities can prioritize their interventions for fixing problems and ensuring high quality urban environmental conditions.

3.1 Applying the Proposed Framework to the Case for Developing a Smart Pedestrian Network (SPN) System

The proposed framework was utilised for developing a dedicated Smart Pedestrian Network (SPN) system to satisfy the needs of municipal organizations and people in their city. SPN aims at overcoming the limitations posed by existing software applications. The purpose is to satisfy the needs of many potential pedestrian user groups, by providing them with relevant information about the pedestrian network. Moreover, through increased awareness, walking is to be promoted and vehicle use is bound to be substituted with active means of transport. In this endeavor it is important to inform potential users on the benefits they can reap from using the proposed Smart Pedestrian Network (SPN) system. Such benefits include increased fitness levels, increased social capital, altruistic satisfaction, reduced vehicle costs, decrease obesity and increased health.

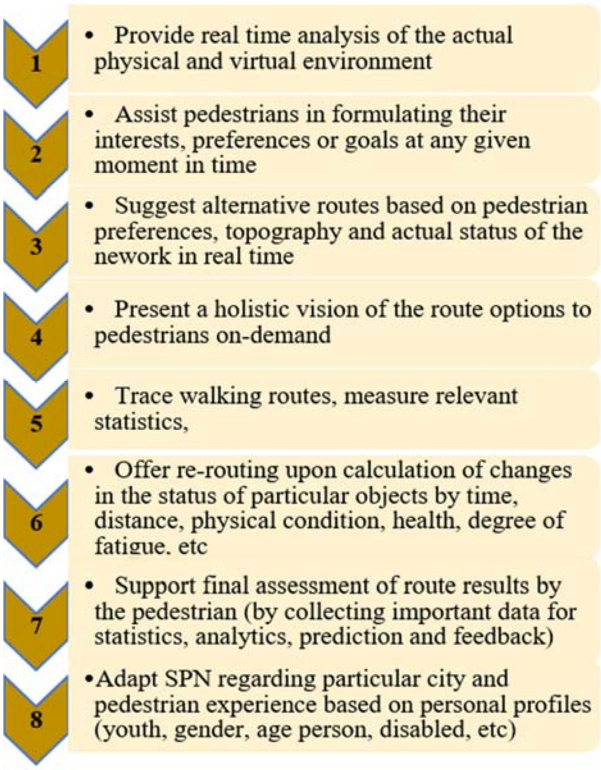

Figure 1: Main Objectives of the SPN Application System

The proposed SPN system should be able to personalise the user interface in order to satisfy specific user needs. For instance, elderly people may wish to be shown a route with amenities such as public toilets and rest places. A tourist may wish to take a longer route that has better sightseeing or cultural events taking place. The SPN application, should able to provide such tailored route suggestions. Current smartphone navigation systems have not been devised to satisfy such user groups with such specific needs. This is where the SPN system comes in, to satisfy these unfulfilled market needs. Put simply, we propose an innovative software system that provides the necessary information and tools to promote sustainable mobility via walking. In this way, we are enabling a feeling of safety and comfort within the urban pedestrian environment. As a result, the proposed SPN system has the objectives that are outlined in Fig. 2.

Additionally, the system structure and the data sources that are used to develop the SPN application are of primary importance. The SPN application is designed to be user-friendly, easy to learn and easy to use by our potential market(s). The data sources must be accurate and reliable. Only then it is ensured that the SPN system can provide users with the most suitable routes and satisfy their personal needs.

Fig.3 depicts the SPN system structure. As shown, the system structure comprises of the pedestrian profile, pedestrian preferences, filters on key journey information, rules for route suggestions, data sources and specific smartphone app functions. Note that the data sources (top part of Fig.3) of the structure is directly connected to the big data framework from Fig.1.

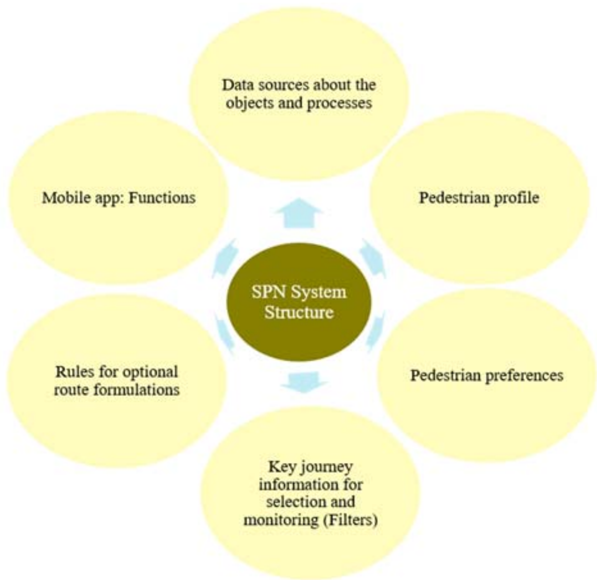

Figure 2: SPN System Structure

The data can also be classified with respect to their state. As shown in Fig.4, there are static data and dynamic data that can be utilized from the urban environment. Static data comprise of attributes such as distance, land metrics, traffic infrastructure etc. Dynamic data on the other hand, comprises of things that are changing over time such as on-going events, maintenance work and changes in weather conditions. Most static data are currently available from open source software such as MAPS.ME and OpenStreetMap. Both static and dynamic data sources could also be provided by the local city mapping service.

The proposed SPN system should have some important features such as information on weather conditions, available amenities in the area and safety conditions during the night. In addition, the SPN system would be able to calculate the number of steps and provide rewards when the user achieves specific milestones. An audio option should also be available for those who are visually impaired. A sharing journey option would create a sense of community and should be available through the smartphone application.

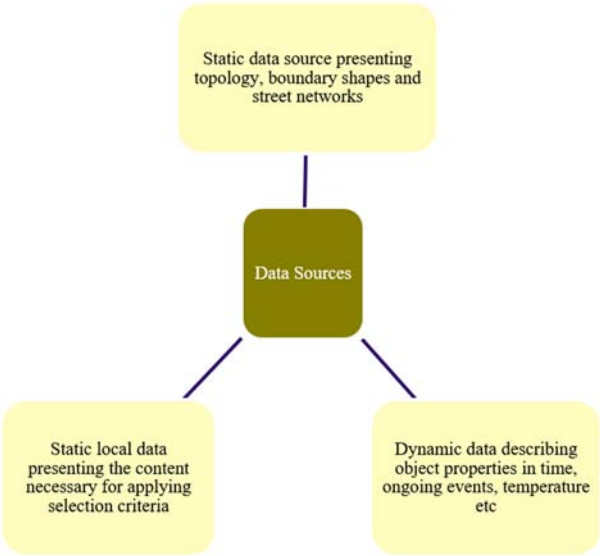

Figure 4: Main Data Sources

In this direction, a chatting service would also be available in order to promote walking together with friends. In collaboration with local cafes, restaurants and retail stores, rewards could be given to those who walk more. Also, information on the effect of walking on CO2 reduction is to be provided. Moreover, the SPN system should be able to handle the uploading of information by the end-users, thus implementing crowd-sourcing schemes. For the promotion of a sense of community, it should easily be linked to Facebook or other social media platforms.

4 Conclusion

This paper reviews the prospect of big data application in an urban setting. As revealed in the literature review, various issues should be considered for successfully implementing such a big data project. This include the motivation of users, data quality, citizens privacy, integration capability, connectivity, trust and a spirit of community among the various stakeholders. The envisioned system, would enable the municipal organization to create successful Big Data applications, so that residents and visitors are properly informed on paths of comfortable sustainable mobility. In turn walking can be promoted with all its positive benefits for individuals, society and the environment.

The proposed big data ecosystem, is applied in the case of developing a Smart Pedestrian Network system (SPN). In this way it was shown that such an approach can support sustainable urban development by promoting active transportation. Active mobility would have positive also for individuals by reducing obesity and providing well-being and a higher quality of life. Based on the experience gained in developing the SPN system it was realised that a stakeholder approach is necessary for successful implementation. Further, tools of open innovation such as co-creation workshops comprising of multiple stakeholder groups were found to be very useful. Involving local businesses, local authorities and organizations as well as various members of the community is absolutely necessary for successfully implementing a big data system such as the SPN.

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