Mobile Phones, Sensors & The Crowd: Lessons Learnt From Development of a Real-Time Travel Information System

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ABSTRACT

This paper discusses the development of a real-time passenger information system that integrates heterogeneous transport information with crowd-sourced vehicle locations provided from mobile devices. We discuss how system development was influenced by combining methods from user-centred design, knowledge engineering, and transport studies. We argue that the combination of such methods is necessary to realise the potential benefit to citizens of Internet of Things applications. This was demonstrated by providing citizens with access to public transport information that otherwise would not exist. We also discuss the systems impact through results of a travel behaviour change study.

Categories and Subject Descriptors

H.3.5 [**Information Storage and Retrieval**]: Online Information Services; H.4.1 [**Information Systems**]: Models and Principles

General Terms

Design, Experimentation, Human Factors, Management

Keywords

Smart Mobility, Crowd-sourcing, Knowledge Engineering, User-Centred Design, Semantic Web, Transport

1. INTRODUCTION

Smart mobility is one area where the Internet of Things (IoT) has potential to deliver benefit to citizens [1, 4]. Improving the passenger experience through effective public transport information is one such scenario, as the availability of information influences the attractiveness and accessibility of public transport [3]. Real-time passenger information (RTPI) systems are used to provide citizens with real-time vehicle locations, estimates of arrival and departure times, and details of disruptions. To provide this, such systems must reason with heterogenous transport information including details of access points (bus stops, bus stations, etc.), descriptions of bus routes, timetables, roads travelled, and GPS-based real-time vehicle locations [2].

Mobile devices also now play a growing role in the provision of access to transport information. This includes accessing details of bus departure times via SMS, smartphone-optimised websites providing details of public transport services, and smartphone apps, such as Moovit[1] and Tiramisu[2]. The latter extend typical RTPI functionality by providing travel experience details based on information crowd-sourced from users, such as vehicle occupancy levels, passenger demand, and details of vehicle faults.

We have developed *GetThere*, a passenger information system designed for rural areas were the infrastructure required by RTPI systems, such as on-vehicle GPS or roadside variable message signs, is typically absent [6]. *GetThere* users are asked to provide observations about public transport, such as vehicle location, via their smartphone. These observations are integrated using linked data principles[3] with various open data sets to deliver RTPI via the same app. Linked data is used as it provides an effective approach for large scale data integration, based on the use of HTTP URIs to identify data and RDF[4], a graph-based machine processable data model. Ontologies are used to provide a schema for RDF data by describing the classes (types) of domain concepts and relationships between them.

Based on the experience developing and evaluating *GetThere*, we argue that to increase the potential benefit to citizens of IoT applications, it is necessary to utilise methods from user-centred design and knowledge engineering. The former provide valuable insights into the desires and limitations of potential users, which influence the development of appropriate computational knowledge models and systems design to satisfy those requirements.

2. DEVELOPING A RTPI SYSTEM

We began by conducting a literature review of existing RTPI systems as an introduction to the domain and to identify common features of such systems. A series of user-centred design and knowledge engineering activities were

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[1] http://www.moovitapp.com/
[2] http://tiramisutransit.com/
[3] http://www.w3.org/DesignIssues/LinkedData.html
[4] http://www.w3.org/RDF/

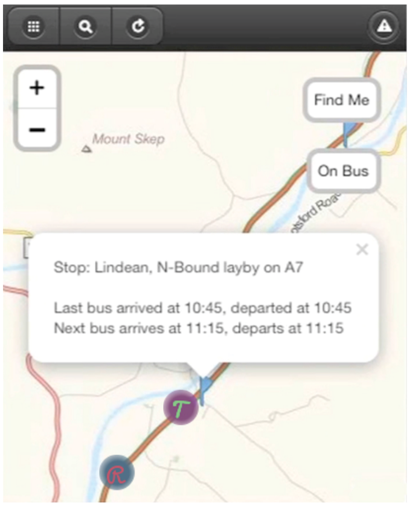
then carried out to develop *GetThere*, co-ordinated to ensure the findings from each influenced future activities.

2.1 User-Centred Design Activities

User-centred design methods were used to engage with end users to ensure their input influenced development of *GetThere*. The first activities investigated the user experience of public transport in rural areas, and explored passengers' existing uses of technology for obtaining and sharing information [5]. This was established though 60 semi-structured interviews with public transport users in the Scottish Borders, transport and social science academic researchers, government agencies, and public transport operators.

These activities found that passengers had a strong desire for real-time vehicle location information, to be notified of disruptions, and support for re-planning journeys affected by disruption. Three information quality requirements were also identified: that it should be timely, accurate, and personalised to the receiver. Technology constraints for the geographic area were also observed, such as intermittent cellular network data signal, potential for excessive phone battery drain, and mobile phone ownership statistics.

These findings were used as the basis for two co-design sessions with rural public transport users in Tiree, UK, during which wireframes for the *GetThere* smartphone app were created. These designs were subsequently refined through user experience prototyping and discussions with the project team. The final design featured four screens: user registration; logging in; viewing of and selection from available bus routes; and map-based visualisation of bus stops and bus locations according to timetable and real-time information (Figure 1). On the visualisation screen, tapping a bus stop displays some timetable information for that stop; tapping the "Find Me" button centres the map on the user's location; and tapping the "On Bus" button starts continuously sharing the user's location as a proxy for the vehicle's location until the button is tapped again to stop the process.



Stop: Lindean, N-Bound layby on A7

Last bus arrived at 10:45, departed at 10:45
Next bus arrives at 11:15, departs at 11:15

Figure 1: Screen shot of the app showing the map-based visualisation of timetable information, location of bus stops (blue flag) and vehicles according to the timetable (purple circle with a green "T") and real-time (blue circle with a red "R").

2.2 Knowledge Engineering Activities

A knowledge engineering approach was adopted to develop the computational model of mobility information necessary to support *GetThere*. The first activity determined the types of information required for *GetThere*, namely: user profiles, bus route names and descriptions, timetables, stop point locations, details of the road network and those roads travelled by buses, and (crowd-sourced) vehicle locations.

A review of existing approaches to represent this information resulted in us defining the model outlined in Figure 2; namespaces correspond to ontologies described below. User accounts are based on the Friend Of A Friend (*foaf:* namespace) and Semantically-Interlinked Online Communities (*sioc:* namespace) ontologies. Route descriptions and timetable information were available as ATCO CIF[5] encoded files, a standard for the interchange of timetable information that forms the basis of the transit ontology[6] (*trn:* namespace). The National Public Transport Access Node dataset[7] and its associated ontology[8] (*naptan:* namespace) provide details of bus stops. OpenStreetMap[9] was selected as the source of road geo-location information. The LinkedGeoData[10] ontology (*lgd:* namespace) is based on OpenStreetMap's data schema, which describes roads as a set of ways, each consisting of a series of nodes (points) described by an identifier and location. We defined a new ontology (*tra:* namespace) to define the routes travelled by buses as a series of nodes. The W3C Geospatial ontology[11] (*geo:* namespace) represents location values. The W3C Semantic Sensor Network (SSN) Incubator Group's ontology[12] (*ssn:* namespace) is extended to model the crowd-sourced location observations and mobile devices (*md:* namespace) by describing them as platforms with attached sensors capable of producing observations about a user's journey on a particular bus route.

Finally, this model was evaluated by applying the queries and update operations required by *GetThere*. This identified an issue regarding the timeliness and accuracy of information, due to the timetable data being updated weekly. This was addressed by refining the model to use the W3C PROV-O ontology[13] to record these update activities, including when they were carried out and the person responsible. This meta-data can be queried to, for example, ensure the most up-to-date timetable data is used. A set of web services was also developed to provide the *GetThere* app's RTPI functionalities by using various data sets.

3. BEHAVIOUR CHANGE STUDY

The purpose of this study was to evaluate *GetThere* in a trial area, including measuring changes in travel behaviour amongst rural public transport users in response to the information they received from the app. 15 participants were recruited (nine female, six male, average age of 28 years) based on their public transport usage (frequency, services

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[5] http://travelinedata.org.uk/CIF/atco-cif-spec.pdf
[6] http://vocab.org/transit/terms/
[7] http://data.gov.uk/dataset/naptan
[8] http://transport.data.gov.uk/def/naptan
[9] http://www.openstreetmap.org
[10] http://linkedgeodata.org/ontology
[11] http://www.w3.org/2003/01/geo/wgs84_pos
[12] http://www.w3.org/2005/Incubator/ssn/ssnx/ssn
[13] http://www.w3.org/ns/prov

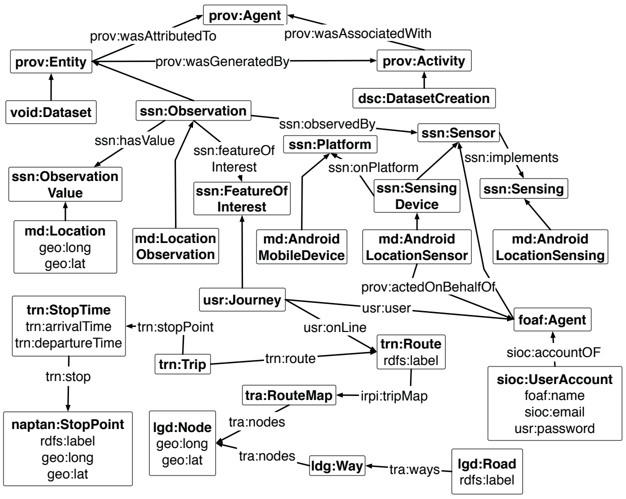

Figure 2: The ontology model developed to support RTPI. Rectangles represent classes, bold lettering indicates the class name, non-bold lettering indicates properties, labelled arrows represent relationships between classes, and unlabelled arrows represent sub-class relationships.

used, and origin-destination points). All participants were students at Scottish Borders College; nine made more than five bus journeys per week. Following selection, each participant's baseline travel behaviour was established using semi-structured interviews, questioning their attitudes to various aspects of the public transport service.

Participants then installed the app on their personal devices and used it to consume and contribute information during their journeys for two weeks. The system was available for eight bus routes in the region, selected based on their connections with the Scottish Borders College and towns served. Following this, participants were re-interviewed using the same questions as previously to allow any deviation in their behaviour to be determined.

Analysis of the interview transcripts suggest some positive impacts of the technology. Participants (numbers in brackets) expressed agreement that the system: increased their sense of control during their journey and journey planning (14), felt it made the bus service easier to use (12), were willing to pay for the information (12), felt it improved the bus service (11), reduced their waiting time (11), and increased their satisfaction with the bus service (10). The transcript analysis also highlighted examples where these can be directly attributable to the design activities. For example, the map-based visualisation made participants aware of stops nearer their destination than they would routinely used, allowing them to adapt their behaviour by alighting the vehicle at the alternative stop. Updating the position of vehicles on the map as each one progressed along the route also gave greater reassurance that the vehicle was operating and would arrive earlier than the paper based timetable information available at a bus stop.

4. CONCLUSION

Successful use of the linked data approach for modelling and integrating heterogeneous information to provide RTPI demonstrates its potential for addressing these challanges in the urban IoT context. The shared vocabularies provided by ontologies simplifies integration of data sets which, along with having data accessible for reuse via the web, reduced the effort required during the knowledge engineering activities, and so reduced development time.

The successful use of the *GetThere* system during the behaviour change study illustrates that commodity hardware and the crowd can contribute to a system that delivers functionalities similar to those of commercial products. The study also indicates the potential of the technology to deliver benefits to citizens in terms of their use of public transport. However, the success of the approach largely relies on developing appropriate incentives for users to become active contributors. This was reinforced during the study when, despite mandatory participation to receive a financial reward, participants did not contribute information during all of their journeys. This suggests that the crowd should ideally be used to enrich the IoT by providing data that existing devices cannot, rather than being used as alternatives to such devices.

We argue that the benefits delivered to participants are attributable to the insights into user requirements and limitations obtained from the design activities and their influence on the design of both the app and the information model developed to support it. All of these activities also benefited from the expertise and experience of domain experts, in our case transport researchers, providing input on, for example, relevant domain data standards and conducting user studies. As such, we argue this combination of expertise and methods would similarly benefit IoT applications in urban areas aiming to deliver benefit to citizens.

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