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A new approach for reducing urban transport energy

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Abstract

Worldwide, 50% of the population already live in cities, and this percentage is expected to rise. Cities account for an estimated 70% of both energy use and fossil fuel CO_2 emissions, and urban passenger travel forms a significant share of this total. This paper introduces a novel approach for reducing both the energy and resulting carbon emissions from such urban travel, in the form of a personal transport energy quota, using a unique cloud technology based intelligent navigation system. The approach has some similarities to the Personal Carbon Trading scheme proposed for the UK some years ago, but is for personal transport only. Like carbon taxes, which have now been introduced in a number of countries/regions, this UK scheme aimed at reducing carbon emissions. The approach proposed in this paper would grant a monthly transport energy quota to all residents. A mobile phone-based application would provide the user with details on the energy costs of each trip, the remaining energy quota at any time, and suggest alternative travel options to minimise trip energy use.

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Keywords: energy credit system; transport energy; urban transport.

1. Introduction

Worldwide, 50% of the population already live in cities, and this percentage is expected to rise. Cities account for an estimated 70% of both energy use and associated fossil fuel CO_2 emissions [1,2], with urban passenger travel forming a significant share of this total. Given rising concerns about both global oil depletion (and energy security in importing countries), and global climate change, it is increasingly important to reduce transport's substantial contribution to both problems. Several options are available in an urban context: shift to more efficient transport modes (public

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transport and walk/cycle); improve the energy efficiency of all transport vehicles; shift to alternative (non-fossil) transport fuels; and stress accessibility rather than mobility [2]. The approach developed here focuses on the first option, and introduces a novel approach for reducing both the energy and resulting carbon emissions from such urban travel, in the form of a personal transport energy quota. The philosophy of this approach has some similarities to the Personal Carbon Trading scheme proposed for the UK some years ago. This scheme proposed to allocate equal tradeable carbon credits to all eligible individuals (who may simply be taken here as all adults), with the aim of reducing carbon emissions, as part of an emissions trading scheme [3].

Similarly, our proposed approach would grant a monthly transport energy quota in megajoules (MJ = 10^6 joules) to all eligible individuals. Overall, this study has several phases. First, we develop the algorithm; second, we prove the concept of such an energy credit system through a series of simulations; third, we implement this system into a mobile based navigation software which is supported by the Urban Transport Energy Saver (UTES) database on the Azure platform. In future, the application will be trialed with a series of tests in Beijing.

Nomenclature

GIS	Graphical information system
GPS	Global positioning system
UTES	Urban Transport Energy Saver
MJ	megajoules = 10^6 joules
RFID	Radio frequency identification
TB	Terabytes

2. Application rationale and description

Large urban public transport systems, with their varied modes, can be very complex. Users are often confused because transport operators seldom provide the information travellers need about their systems in a simple, easy-to understand format. Google, in conjunction with transit operators, developed the Google (now General) Transit Feed Specification which has become 'a *de facto* standard for exchanging transit schedule data' [4]. Tranport operators from the original program have also released their own tranport timetables in this format for others to develop further [4]. Given the ubiquity of smart phones, other researchers have looked at how mobile applications might improve the usability and convenience of public transport, both for regular users and for those such as the disabled. In the remainder of this section we first present the algorithm, then discuss its use in the transport energy quota application.

2.1 The algorithm

Let:

E_{n-1} total energy consumption quota (MJ) remaining in account after *n-1* trips in that month

E_n total energy consumption quota (MJ) remaining in account after *n* trips in that month

e_n energy consumption (MJ) of trip *n*

d_n travel distance (in route km) for trip *n*

R_n traffic condition coefficient for trip *n*

X annual average unit energy cost for one km of car travel (MJ/km)

Y_n transport mode coefficient (ratio of energy use per km by actual mode to *average* car energy use) for trip *n*.

The non-dimensional coefficient Y_n will vary both from city to city, as well as by time of day. Comparative data suggest that the energy efficiency of public transport in Asian cities is much higher than in USA or even Western European cities [5]. Unlike car travel, public transport follows scheduled timetables, so that the marginal energy use of an extra passenger is very small, especially when fully loaded. It seems best, therefore, to use the annual *average* efficiency for each public transport mode in a given city, to cover the fixed energy costs of a given timetable. (Further, using marginal energy efficiences would encourage even more use of already-crowded peak hour services, rather than off-peak services which may still have spare capacity.) In 1995 in Beijing, for example, average public transport energy efficiency (in passenger-km per MJ of primary energy) was about six times that of private car travel, so that in this case Y_n is 6.0. For the non-motorized modes (walking and cycling), Y_n is set to zero. R_n, another non-dimensional coefficient, will vary by time of day for car travel, being >1.0 for peak hour travel and <1.0 for off-peak travel. For public transport modes, for reasons just given, R_n is set at 1.0 for all times of the day. Other non-dimensional coefficients can be included in the algorithm, if found to be important in a given urban area. For example, different public transport modes could have different Y_n coefficients. For private travel, another coefficient could be applied to X, to account for different energy efficiencies for different cars.

The energy cost for the planned trip *n* is thus:

$$e_n = X.d_n.R_n.Y_n \tag{1}$$

Further:

$$E_n = E_{n-1} - e_n \tag{2}$$

The algorithm then checks if the remaining energy account E_{n-1} is > the energy consumption of trip *n*.

Three different situations arise:

(1). $E_n \geq$ the total energy consumption of using private car *every* day (calculation based on the user's average travel distance and traffic conditions etc) for the remaining days. The user could continue to use any type of transport, but public transport and bike/walk are also suggested.

(2). $E_n \leq$ the total energy consumption of using private car every day (calculated as for (1)) for the remaining days but is $\geq$ the total energy cost of using public bus/metro every day. Therefore the traveller should use public transport, or even better, use green transportation (bike/walk) to save some energy credits for future private car travel.

(3). E_n < the total energy consumption of using either car or public bus/metro every day (calculated based on the user's average travel distance and mode etc) for the remaining days. Therefore the user should only use bike/walk to save energy credits so he/she may use a motorized transport mode later. After the navigation process is finished, a possible smart travel suggestion will be displayed on the website for the following days.

2.2. Application description

The UTES tool suite discussed here aims for general usability by providing a broad set of interface options, but with particular focus on pre-trip information as opposed to in-trip guidance. The ultimate goal for UTES is to develop a platform whereby every urban sensor, device, person, vehicle, building and street can be potentially used to probe city dynamics to enable city-wide computing that serves the population's travel activities. UTES aims to enhance urban transportation through an iterative process of sensing, data mining, understanding and improving urban transport systems. In the following sections, the system architecture, design, and implementation of UTES are discussed. The design of UTES focuses on interactive visual analytics to provide the user with the most appropriate information. The design will eventually consider factors such as urban residential density, travel styles, alternative options, costs, time restraints, travel experience, etc.

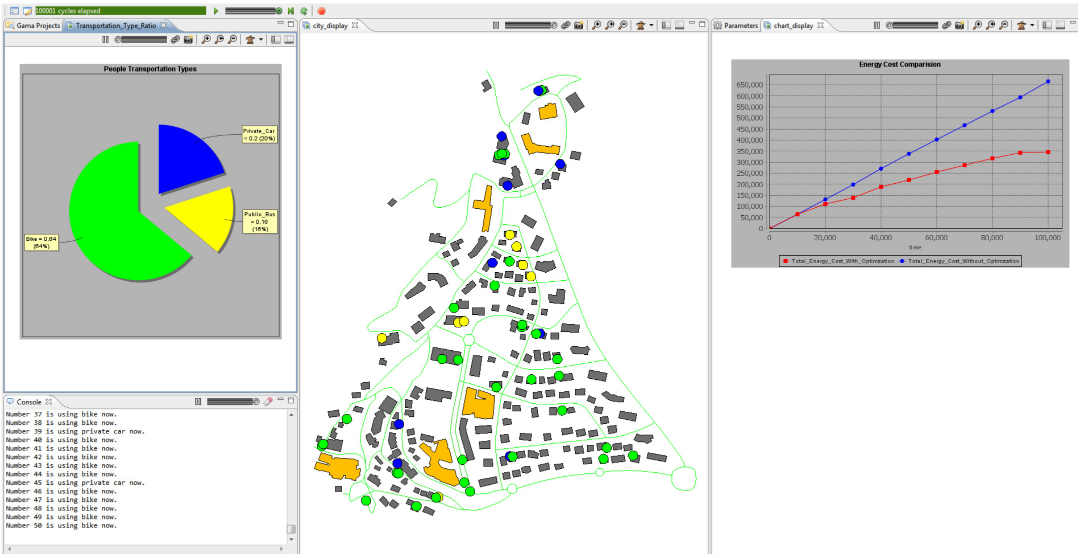

Figure 1. UTES project, travel simulation for a given trip

In contrast to traditional urban transportation systems, UTES leverages the *cloud* to profile and optimize data classifiers for mobile devices, depending on the current device context and sensor data characteristics, in order to provide interactive visual analytics for supporting decision making. This project focuses on analysing and mining dynamic information.

Recently, there is a trend to using a combination of real-time Global Positioning System (GPS) and Radio Frequency Identification (RFID) sensors deployed in vehicles, together with static city sensors and cloud service to optimize eco-efficiency [6]. This approach can embrace a wide range information from static sensors such as street cameras, traffic lights location and cycles, speed of cars, road lighting, temperature and general weather information and from vehicles themselves, including car speed and GPS location information. This allows optimal management of vehicles and traffic in real-time, potentially improving system energy efficiency.

The application will be developed and examined through a series simulations based on real Graphical Information System (GIS) data, potentially with real-time data feeds. As an example, Figure 1 shows an indicative travel simulation within a simulated urban environment for a given trip. In the window in middle of the screen, the following elements are presented:

- A GIS map, with the lines presenting roads in the area. The color of the roads roads changes with traffic volumes, with green representing lightly-trafficked roads.
- Buildings are currently classified on the map as either public/business (yellow) residential (grey)
- Users (current travellers and trip planners) are represented by circular dots on the map; there are 50 users in total in this simulation
- Transport modes are represented by different circle colours This simulation has three modes: private vehicles (blue), public transport ie buses, trains or underground rail (yellow), bicycle/walk (green).

The top left corner graph gives the transport mode share: blue for car (20%), yellow for public transport (16%), green for walk/bicycle (64%). The bottom left corner lists the mode currently used for each traveller. The top right corner graph gives the energy consumption of the overall transportation system by those travelling. The blue curve shows maximum energy consumption assuming all travel is by private vehicles, the red curve energy consumption optimized by UTES method. As the result of implementing UTES method to optimize transport, the energy consumptions savings are significant.

UTES provides users with a variety of interface options, and the underlying implementation and technology stack is quite diverse as a result. The UTES server back-end is written in Java and uses a variety of standard open source development libraries and frameworks for its implementation. The system is composed of a number of service modules, each providing specific functionality, coupled together.

In order to verify the performance of the proposed algorithm, a web-based navigation system was developed. The map information used is the open source map from Baidu platform.

1. After the user has registered online, a unique user database is created in the Azure Platform. In the database, one table stores the user's current energy quota, another stores the travel logs.
2. The navigation website at present provides for three different transportation types: Private car, public transport, and walk/cycle. Once the origin and destination and transport mode are selected, the total trip energy use will be provided immediately from the Baidu platform.

3. Discussion

The next step is to trial the application in Beijing. For these planned tests, the transport energy quota will be voluntary only, although it will be set at a lower level than the present average per capita transport energy use in Beijing. The quota, can, of course, be adjusted downward as needed.

In this next stage, the researchers intend to use real data for this simulation. To enable such real analysis, we have successfully reserved 15TB data storage from Microsoft Azure cloud platform to satisfy the needs of analysing annual Beijing road traffic data (about 12TB per year). This data will include both GPS and loop detector data feeds. There are over 20 million people in Beijing; if 5% use the system on average twice a day, then visits total two million per day. Assuming uniform daytime distribution (about 10 hours), the system must be able to meet about 60 access requests per second, with perhaps 300~500 times per second during peak hours.

In the trial, there will be no costs incurred for exceeding the monthly quota, so that any travel energy reductions will be voluntary. For OECD countries, achieving such pro-environmental behavior in transport has been found to be much harder than it is for domestic energy [7]. But Chinese cities are very different from most OECD cities in that air pollution levels are far higher [8], and urban air pollution is accordingly rated a very serious and immediate problem by residents [9]. In contrast, global warming is seen as a more remote problem. Nevertheless, China plans to introduce a nation-wide carbon market in 2015, and already has a pilot program in place [10]. It also has an ambitious renewable energy program. The combination of local and global oil depletion, climate change and, especially for Chinese cities, serious local air pollution, make the UTES approach both relevant and timely.

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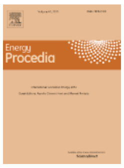

Biography

Stephen Jia Wang (research: Tangible Interaction Design, behavioral changes for sustainability) is Senior Lecturer, Director of Tangible Interaction Design Lab (ITIDlab) and Program Director in Interaction Design; Patrick Moriarty (research: energy, transport, global futures) is Adjunct Associate Professor, both in the Department of Design, Monash University, Australia.