PREDICTION OF LINK TRAVEL TIMES IN THE CONTEXT OF NOTTINGHAM'S URBAN ROAD NETWORK

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Abstract: Traffic congestion is becoming a serious environmental threat that must be resolved quickly. Traditionally, travel information systems have been specific to a particular mode of transport. For instance, traffic information (road conditions broadcast) has been directed at drivers. Instead, travel information systems are now being developed which incorporate route guidance systems to divert drivers away from the congested areas either by change of travel mode or travel route. The mobile travel information system developed at The Nottingham Trent University enables progression from a passive mode of interaction between traffic control systems and road-users (one-way flow of information) to an active mode. The integration of data concerning traffic flows and individual journey plans thus makes it possible to perform optimisation of travel. This paper focuses on the issue of provision of real-time information about urban travel and assistance with planning travel. Nottingham's SCOOT (Split Cycle Offset Optimisation Technique) traffic-light control system provides real-time information about the link travel times within certain areas of the city. However, rather than using link travel times at the time of the request, it is more effective to predict the link travel times for the time of travel along the particular links. The future link travel times depend upon the historical travel time of the link (for the specific time step in the day) as well as the current link travel time. Consequently, the link weights are a combination of real-time data, historical data and static data. The prediction method will be validated in the context of Nottingham's urban road network. The results will be presented at the conference.

Keywords: Transportation, Optimisation, Efficiency, Prediction methods

1. BACKGROUND

Traffic congestion is becoming a serious environmental threat that must be resolved quickly. Great Britain has become a role model in the battle against global pollution. The Prime Minister, Tony Blair, has acknowledged that a 20% reduction in carbon dioxide emissions in Great Britain is a credible target for the year 2010 [Brown, 1997]. However, significant measures are necessary to attain this target. Road vehicles and industry are the main sources of pollutant emissions. In the United Kingdom, road vehicles are responsible for over 50% of the emissions of nitrogen oxides and over 75% of carbon monoxide emissions [DETR, 1998]. Congestion is already a major problem in many areas and traffic volume is set to grow by 30% in the next 20 years [MacAskill, 1999].

Indeed, in 1996-1998, the average person in Great Britain made over 1000 journeys per annum. This is a substantial increase when compared with the figure of 742 journeys made per person per annum in the period 1992-1994. Although the average citizen is clearly becoming more mobile, the distance travelled by an average person in a year has not changed significantly. The greatest average distance travelled per person per annum is for the purpose of commuting, closely followed by visiting friends at home [Keynote, 1999]. The largest increases in the number of journeys per person are connected with education. By optimising such journeys, the cumulative emission of vehicles will be curtailed.

This paper describes the infrastructure that is currently being developed at The Nottingham Trent University to facilitate multi-modal travel throughout the city of Nottingham. This paper focuses on the issue of provision of real-time information about urban travel and assistance with planning travel. This includes consideration of uncertainty about traffic delays, inconvenience of parking and the variability of travel time along urban links.

2. TRAVEL INFORMATION SYSTEMS

Traffic/travel information is inherently heterogeneous and is characterised by varying levels of information granularity: from detailed lane occupancy data through to video traffic surveillance to travel times of specific journeys using various modes of transport. Recent advances in computing and communications have made it

feasible to access all of these important sources of information. However, the integration of this information for the purpose of optimising urban travel with respect to various environmental, social and economical criteria remains an unanswered challenge.

There are a number of ways of informing travellers about the location of congestion areas – such as, radio or television broadcast and variable message signs. The growing body of opinion, that the traditional forms of supervisory control are both too expensive and inaccurate, prompts new development. The traditional forms require full involvement of a human operator. However they do not take into account the specific requirements of individual journeys. In particular, because of the protection of privacy, the crucial information about the intended destinations of individual vehicles is not normally available to these controllers and, even if it was, it could not be processed efficiently. On the other hand, an attempt to delegate the responsibility for journey optimisation to road users by informing them (through radio broadcasts or variable message signs) about the best routes, that are relevant to various journeys, is bound to be counterproductive because of the resulting information overload.

Traditionally, travel information systems have been specific to a particular mode of transport. For instance, traffic information (road conditions broadcast) has been directed at drivers. While fulfilling its intended objective, such an approach to urban travel support does little to encourage multi-modal travel in the cities.

To eliminate these constraints, this research project takes a fundamentally different approach and rather than aiming at maximising the efficiencies of the use of individual modes of transport taken in isolation, it considers a broader multi-modal travel framework. Travel requirements are defined in terms of journeys and the mode of travel is just one of the decision variables. An important feature of our approach is that it recognises the individual nature of journeys. The enquirers are able to select their journey according to their individual preferences, such as the importance of a short journey time or the importance of timely arrival at the destination. Although the answers may be highly subjective it must be remembered that it is precisely these preferences that make people opt for one mode of transport or another. In this sense, multi-modal travel optimisation offers good mapping onto human decision-making.

2.1 Conventional Systems

Travel information systems are now being developed which incorporate route guidance systems to divert drivers away from the congested areas either by change of travel mode or travel route. Dynamic guidance is of the greatest benefit to travellers, as new routes and travel modes can be suggested as conditions change [McDonald and Montgomery, 1996]. The system will aid the road users by providing access to information that is not readily observable form the current location of the traveller, yet is relevant because of the planned journey. The wide use of such a system will reduce the amount of congestion within the city, by the choice of departure time and shorter routes as suggested by the route guidance system. This will lead to expected reductions of pollutant emissions in currently congested and critical areas.

The system enables progression from a passive mode of interaction between traffic control systems and road-users (one-way flow of information) to an active mode. Within the active mode, the road users supply the information about their intended destination (without disclosing their identity) and, in response, receive customised traffic information that optimises their journeys.

Traveller information solutions aimed at Internet users have been developed. However the Internet's communication delays cause problems due to the dynamic nature of urban traffic and with access limited to the home/office or the few available travel information terminals, the accuracy and the relevance of the advice is limited. At the other end of the spectrum, travel information systems incorporated in top-of-the-range cars, offer excellent static travel information but are limited regarding the real-time traffic and public transport data provision and as such do not contribute directly to mode switching decisions by drivers [Bargiela et al., 1999].

2.2 Real-Time Systems for Mobile Users

The system must be capable of simultaneous data acquisition, processing and dissemination of the traffic/travel advice in real-time to a full spectrum of end users. Preston et al. [1993] proposed the use of in-vehicle telephones to communicate with a remote computer. The increasing use of mobile phones by the general public takes their suggestion one step further, opening access to the decision support system to many more users. The integration of data concerning traffic flows, public transport and individual journey plans thus makes it possible to perform multi-modal optimisation of travel.

So, there is a need for a hierarchical urban sustainability structure that would be specifically responsible for providing a global optimisation layer while relying on the local optimisations affected by the individual organisations responsible for urban transport [Peytchev and Bargiela, 1998; Pursula, 1998]. The development of such a structure should clearly rely to a maximum extent on the standard computer and public communication systems. However, the feasibility of such an undertaking has to be proven by detailed consideration of the technological constraints of the sub-systems that are to be integrated.
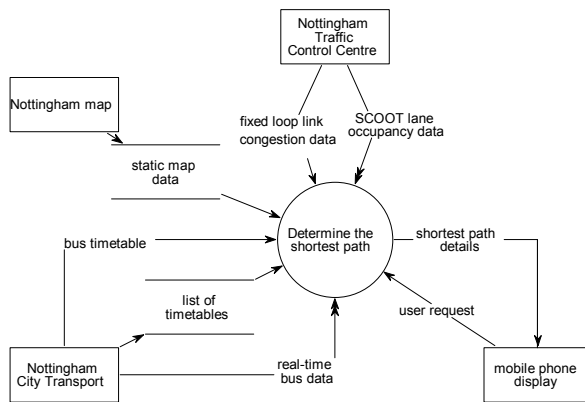

Figure 1. Determining the shortest path

The developed structure is a Distributed Memory Environment (DIME) [Peytchev and Bargiela, 1998] that manages the data from a number of sources (Traffic Control Centre, public transport company and the user) (Figure 1). Nottingham Traffic Control Centre continues its kind agreement of allowing the Intelligent Simulation and Modelling group to have access to its Traffic Control System (SCOOT and congestion data), providing the necessary current traffic information. Nottingham City Transport has obligingly approved the use of the necessary information concerning their bus timetables.

The user communicates with the DIME system via a mobile phone. The advantage of a mobile phone is that there do not exist the constraints of being part of a car's equipment or being deployed at a particular location. Along with the increasing use of mobile phones by the general public, this means that the system has a much broader user base. By implication, this will result in a much greater impact on travel mode switching decisions [Bargiela and Berry, 1999]. Also, the system is easy to use and not prohibitively expensive.

3. ROUTE GUIDANCE

There are many methods of path finding that are appropriate for use within the spectrum of route guidance. Some of these methods have been considered and evaluated in the context of multi-modal travel in Nottingham's urban network. The results are published in [Hartley and Bargiela, 2001; Hartley, 2003]. This paper concentrates on the delivery of timely route guidance given the available real-time traffic information.

3.1 Urban Network Information

The pre-requisite to determining any shortest path in an urban network is having information about the road link weights (Figure 4).

The necessary input data, mostly provided by the different organisations managing the urban network, comprises SCOOT (Split Cycle Offset Optimisation Technique) link data, congestion data for fixed loop links and static map data (Figure 1).
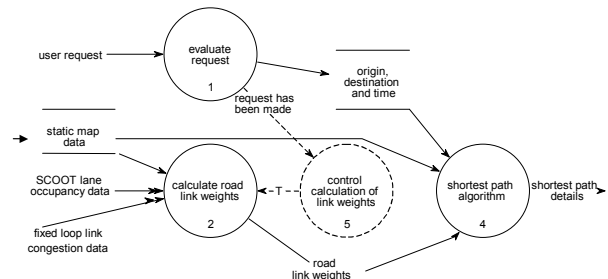

Figure 4. Calculation of travel along links

SCOOT is an intrinsic part of Nottingham's traffic-light control system comprising induction loops that detect the presence of vehicles in real-time. The SCOOT link data provide real-time information about the link travel times within certain areas of the city. Fixed loop congestion data again provide real-time information – these data are specific to certain junctions or roads (distinct from the SCOOT-managed areas). The static map data include information about the topology of the urban network and the length of roads. The integration of SCOOT lane occupancy data (leading to link times in SCOOT-managed areas), fixed loop congestion data (leading to link times in some non-SCOOT areas) and static map data (providing estimated static data of the link times for the remainder of the network) are manipulated into up-to-date, reliable information of alternative paths and adverse traffic conditions on appropriate links. This enables the derivation of the optimal route for travel by car.

3.2 Travel by Car

Dijkstra's algorithm [1959] has been used to determine the optimal route by car. Dijkstra's algorithm builds an expanding list of examined vertices and looks at paths through vertices on the list. The path with the smallest total of link weights is incrementally found.

Dijkstra's algorithm

pathlength(all links) = ∞
marked(all links) = .false.
marked(origin) = .true.
pathlength(origin) = 0
do for all links until marked(destination) = .true.
{
search for all pairs of nodes s.t.
marked(node1) = .true. & marked(node2) = .false.
then
pathlength(node2) = min[pathlength(node2),
pathlength(node1)+length(node1,node2)];
from this set determine which node2 has minimum
pathlength then
marked(node2) = .true.
}

Rather than using link travel times at the time of the request, it is more effective to predict the link travel times for the time of travel along the particular links. The method used was developed as part of the Ali-Scout project [Kotsopoulos and Xu, 1993]. The future link travel times depend upon the historical travel time of the link (for the specific time step in the day) as well as the current link travel time. The process is as follows:

$$D = \frac{T_h(l,n)}{T_{cur}(l,n)} \qquad (1)$$

where $T_h(l,n)$ is the historical mean travel time of link l at time step n
and $T_{cur}(l,n)$ is the current (time step n) travel time at link l.

$$T_p(l,m) = \frac{T_h(l,m)}{D} \qquad (2)$$

where $T_p(l,m)$ is the predicted travel time of link l at future time step m.

As the state of the network can change extensively in a short period of time, a combination of real-time data and historical data should be used, with the proportions dependant on the expected time taken to arrive at the measured link [Kotsopoulos and Xu, 1993]. Kotsopoulos and Haiping [1993] propose information discounting:

$$T_p(l,m) = a * T_h(l,m) + (1-a) * \frac{T_h(l,m)}{D} \qquad (3)$$

where a is an increasing function of *(m-n)*, say $e^{(m-n)}$.

Consequently, the link weights are a combination of real-time data, historical data and static data (Figure 5).
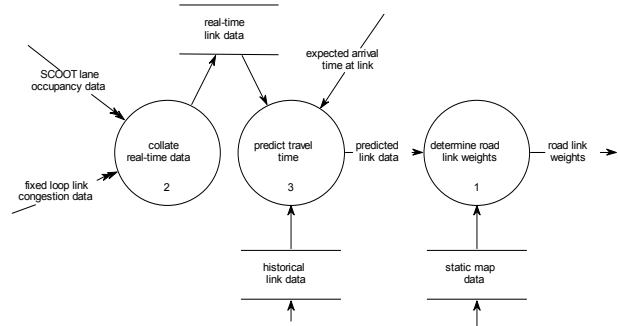

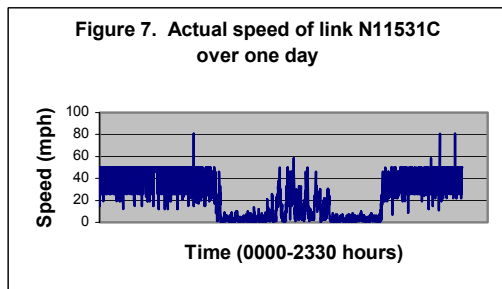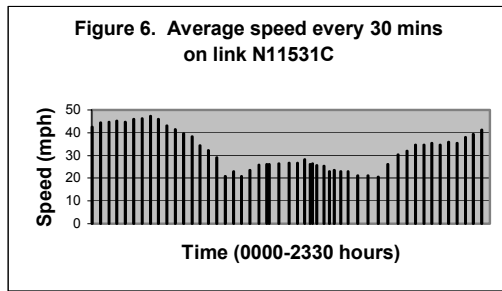Figure 5. Combination of historical, current and static data

4. REAL URBAN TRAFFIC NETWORK APPLICATION

Currently, the available real-time information in the Nottingham urban network is collected from SCOOT detectors, which monitor highly traversed links within the city centre and the arterial routes into the city. 100 links out of 2018 are currently equipped with SCOOT inductive loop detectors. The SCOOT data consists of a large amount of traffic control information relayed in the form of messages [Siemens PLC, 1997] (which include information about flow, occupancy, delay and speed etc.). The U06 message provides information every 30 seconds about the average point-speed of a car travelling along a link (measured over the last 5 minutes). This speed and knowledge of the link length is used to estimate the current travel time of the link.

5. RESULTS

As some of the routes across Nottingham may take up to one hour to traverse, it is not sufficient to use the current travel time estimations. So, instead predictions of travel time will be used (as described in section 3.2). The available historical U06 messages will be used to determine the validity of the prediction method in the context of Nottingham's urban network. The results will also show how the incorporation of real-time information routes traffic away from congested areas. It will also be shown that the method is

capable of dealing with the transition between peak and off-peak conditions.

Figure 6. Average speed every 30 mins on link N11531C

Figure 7. Actual speed of link N11531C over one day

Figures 6 and 7 show that the historical speed cannot be relied upon, as the speeds fluctuate even on a single link on a single day.

The efficiency of the algorithm is of paramount importance, so that the information provided to the user is timely and thus relevant. For Nottingham's network of 597 nodes and 2018 links, Dijkstra's algorithm has a system run-time of 0.4 seconds. The execution time of the predictive route finder algorithm should not be greater than a few seconds.

All of the above results will be presented in detail at the conference.

6. DISCUSSION

It should be noted that minimisation of travel time by car does not necessarily produce the optimal route from 'door-to-door'. With the increasing ownership of cars, there is more demand on the limited number of parking spaces within any city. Consequently, the inconvenience of parking can make travel by car be less preferable especially for those travellers who are particularly adverse to travel time uncertainty. So users may ultimately be encouraged to travel by public transport instead. This becomes especially apparent when travel advice includes both car and public transport as modes of transport, as is the case in the developed real-time travel information system detailed in section 2.2.

7. CONCLUSIONS

This work is part of a study exploring the provision of traffic and travel information through mobile communications. This paper has clearly shown that the communications infrastructure has been successfully implemented.

This paper demonstrates the necessity of real-time information when providing traffic/travel information to the general public. The use of real-time data provides the user with information about the state of the network, not normally foreseeable by the traveller.

8. FUTURE WORK

The car guidance system should be tested on a suitable simulator before being implemented in the real world. The Simulation and Modelling Intelligence group at The Nottingham Trent University [Peytchev and Bargiela, 1994; Peytchev and Bargiela, 1995] has developed a suitable microscopic traffic flow simulator. Any private vehicle route guidance system must consider the inherent implications for the rest of the urban traffic network. It must be ensured that the movement of traffic from one area of the network does not result in congestion of another area of the network. Investigation into induced traffic has already shown that road improvements will normally result in a traffic growth of 10% in the short term and 20% in the longer term [Goodwin, 1996].

Studies have shown that the acceptance of route guidance is strongly correlated to any previous experience of the system. Simulation will be used to test how the use of the route guidance system will enhance the progression of the traveller [McDonald et al., 1995].

Due to the large amounts of static and real-time data that will be used by the path finding algorithm, there are a number of issues to investigate with regard to storing information. The appropriateness of storing set paths, or calculating paths on demand will be investigated. The pruning of the urban network will be necessary – this may be achieved in a pre-processing mode or as part of the algorithm. Also, further analysis of multiple users (of the order of 100) will need to be considered to continue to provide a viable service. Some possible long-term solutions are the use of more processors, parallel algorithms, or some form of artificial intelligence (such as neural networks).

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