PERSONAL ADVANCED TRAVELER ASSISTANT

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Abstract: In spite of numerous road management schemes and developed infrastructure the society nowadays still faces the problem of highly congested roads due to the increasing traffic demand. The focus of this paper is to develop a complex and integrated system that addresses the challenges of dynamic traffic assignment in modern times. We built a design for a Personal Advanced Traveller Assistant (PTA). The main purpose of PTA is to give routing advices depending on the users preferences and the available capacity in the network. The system incorporates a dynamic traffic algorithm that employs a prediction model of future travelling time. The prediction model that the algorithm uses is based on historical data. To conclude, we successfully implemented a working prototype that uses various technologies such as Java, the Open Street Map API for rendering the map or J2ME for the mobile phone client.

1 INTRODUCTION

In July 2007 the Federal Highway Administration and National Cooperative Highway Research Program in US sponsored a scanning study to examine congestion management programs and policies in Europe (Dantzig, 1957). This program included four countries: Denmark, England, The Netherlands and Germany. The focus was on the traffic parameters and on the measures for the deployment of congestion.

The traffic growth in The Netherlands is about 3 percent per year. In order to show some statistics, The Netherlands reports congestion costs of 0.8 MEuro per year. The accessibility of main ports is also affected. There is a critical need for traffic congestion management.

From 1989 onwards, various traffic management measures were implemented, starting from motorway traffic management systems to overtaking prohibitions for trucks and special police teams for rush hours. The efforts undertaken so far to improve the existing traffic network through traffic management schemes by the government in The Netherlands are the following, see Figure 1 and Figure 2: Queue warning; Speed Harmonization; Temporary Shoulder Lane use; Dynamic Lane marking.

The dynamic nature of traffic can be observed in both temporal and spatial changes in the traffc demand, roadways capacity and traffic control parameters. The traffic demand increases over time until peak periods, it varies stochastic during the peak hours and decays at the end of peaks.

A great part of the congestions are regular and recurring at certain locations of the freeway network and also at certain hours. These add up with the incidents, the road maintenance fields, the weather conditions and special events that impact traffic.

Most GPS devices that people own, when requested a route, provide a solution based on the minimum distance. People usually hear on the radio if there is an incident or if there is something special happening on the motorways. But then they have to estimate themselves which alternative route they should choose, how much extra time they have to spend, whether a certain alternative is the most convenient one and so on.

How can we best define the dynamic traffic assignment? It can be described by the process of dynamically selecting a path made out of roadway segments from a trip origin to a trip destination depending on a cost function. The cost function is usually the travelling time.

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Figure 1: Examples of traffic management measures in The Netherlands.

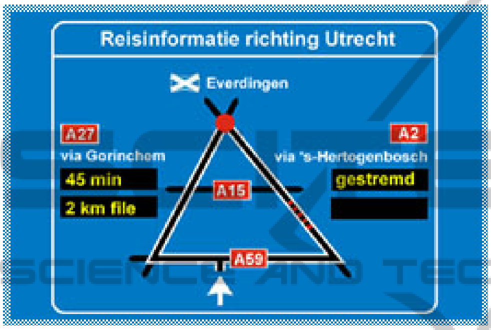

Figure 2: Dynamic route information.

The complexity of traffic management is due to the interaction of three main processes (Kemer, 2004):

• the traveller's decision behaviour, as the decisions of drivers influence the outcome of the traffic network;

• the dynamic traffic assignment in a traffic network;

• the traffic flow behaviour, in particular when incidents and accidents occur in the network.

One approach to solve the congestion issues and though to reduce the travel time for individuals is to develop a route planner that incorporates current and future traffic information when searching for the best route. When congestions or incidents occur on this route the planner has to compute the best alternative solution which may lead the driver on different roads or to a train station. The main purpose is to minimize the travelling time by taking into account the changes and the future situation in the traffic network. In this area the personal advanced travelling assistants play a crucial role. Such an assistant has multiple functions including that it computes the shortest travelling time-routes based on current information received from traffic.

Within the research program Seamless Multimodal Mobility at Delft University a Personal Intelligent Traveller Assistant (PITA) has been designed.

The outline of the paper is as follows. In the next section we will describe related work on dynamic routing. Next we will describe the used databases of historical travel times. Next to open sources we used to build our prototype. Then we describe the main part the dynamic routing algorithm. We report some experimental results and end up with a conclusion.

Figure 3: Car drivers use PITA to plan a trip.

2 RELATED WORK

Traffic assignment is defined as the problem of finding traffic flows given an origin-destination trip matrix and a set of costs associated to the links. One solution for this problem is either that the driver drives on the optimum path according to his preferences, known as the User Equilibrium (UE) assignment or alternatively the path that minimizes the overall network's travelling time, known as the System Optimum (SO) assignment.

(Wardrop, 1952) was the first one to differentiate the two methods. A spectacular example that actually shows that the UE assignment is in general different from the SO solution is the Braess network. The mathematician Dietrich Braess obtained the paradoxical result that the addition of an arc to the network can result in increased origin to destination and overall travel cost. (Fisk, 1979) studied the Braess paradox more in detail. She presented the sensitivity of travel costs to changes in the input flows while they are in Wardropian equilibrium. Examples which state the fact that an increased capacity of the input flow can decrease the travelling time are presented.

Non-equilibrium methods assign traffic to a single minimum path between two zones. The minimum path infers the minimum travel time. Minimum path algorithms include for example the models developed by (Dantzig, 1957) and (Dijkstra, 1959). Other non-equilibrium methods include diversion models, multipath assignments and eventually combined methods.

Equilibrium methods are algorithmic approaches which assume equal travel times. They are optimal assignments since they are formulated on the basis of linear or nonlinear mathematical programming (Matsoukis, 1986). The user optimum equilibrium can be found by solving a nonlinear programming problem.

When a time dimension is added at the models previously described then the DTA is obtained. Thus, by including temporal dimensions we can represent the real life traffic situation and compute the traveling time. Literature surveys in this field generally mention two main approaches for DTA: the analytical-based models and the simulations.

The first approach which is the analytical-based approach model considers two time indices: the time at which the path flow leaves its origin and the time at which it is observed on a link. In other words, the approach assumes that the whole time is divided in intervals. Then, static mathematical analytical control models are applied to each interval, on the assumption that one interval is long enough so that drivers can complete the trip within that certain time interval.

Literature within this area of research is extensive. DTA has evolved a lot since the work of Merchant and Nemhauser (Merchant and Nemhauser, 1978) who considered a discrete time model for dynamic traffic assignment with a single destination. The model they assumed was nonlinear and non-convex.

Meantime, researchers became aware that DTA theory was still undeveloped and necessitated new approaches to account for the challenges from the application domain. DTA comes across a large set of problems depending on various decision variables, possessing varying data requirements and capabilities of control.

The second approach is the simulation-based model. This approach simulates the behaviour of the drivers in different traffic settings. Due to their capability of better representing the real world they increased their popularity. Simulations usually try to replicate the complex dynamics of the traffic. Although that this is considered a different approach, the mathematical abstraction of the problem is a typical analytical formulation.

Next we consider some analytical-based approaches and mathematical programming models for DTA from literature. (Ziliaskopoulus, 2000) split the analytical models from literature in four broad methodological groups where the first ones are the mathematical programming formulations. Within this approach flow equations are deducted and a nonlinear mathematical programming problem has to be solved. (Merchant and Nemhauser, 1978) and (Ho, 1980) studied such models. Due to the complexity of a nonlinear problem, a linear version of the model with additional constraints can be created and solved for a global optimum using a simplex algorithm. The linear program has a staircase structure and can be solved by decomposition techniques.

In optimal control theory the routes are assumed to be known functions of time and the link flows are considered continuous functions of time. The constraints are similar to the ones at the mathematical programming formulation, but defined in continuous-time setting. This results in a continuous control formulation and not in a discrete-time mathematical program. (Friesz et al., 1989) discuss two continuous link-based time formulations of the DTA for both the SO and UE objectives considering the single destination case. The model assumes that the adjustments of the system from one state to another may occur while the network conditions are changing. The routing is done based on the current condition of the network but it is continuously modelled as conditions change. The SO model is a temporal extension of the static SO model and proves that at the optimal solution the costs for the O-D used paths are identical to the ones on the unused paths. They established as well a dynamic generalization of the well known Beckmann's equivalent optimization problem.

Simulation environments address key issues of the traffic assignment, such as the flow's propagation in time and the spatio-temporal interactions. Contemporary DTA models were developed using different traffic simulators (such as CONTRAM (CONtinous TRaffic Assignment Model), DYNASMART or SATURN etc.). SATURN, (Vliet and Willumsen, 1980) is an early DTA simulation tool that uses an equilibrium technique.

The CONTRAM, (Taylor, 1980) simulation environment is more dynamic than the previous ones as it allows the re-routing of cars if traffic conditions worsen. However, it does not consider a maximum storage capacity for roads and it assigns cars only based on the Wardropian principle. DYNASMART is a contemporary DTA model which uses the basic CONTRAM concept. (Abdelfatah and Mahmasanni, 2001) show an example of a DTA model developed by the DYNASMART approach.

(Lum at al., 1998) showed that the average speed depends on the road's geometry, on the traffic flow characteristics and on the traffic signal coordination. A new travel time-density model was formulated by incorporating the minimum-delay per intersection and the frequency of intersections as parameters. The travelling time and the traffic volume are two main field items that have to be considered for the speed flow study along arterial roads.

Most influencing factors that have been cited in literature are the special incidents and holidays, signal delays, weather conditions and the level of congestion. The prediction error might be also directly proportional with the length of the forecasting period (Kisgy and Rilett, 2002).

Most of the short-term forecasting methods that were used in literature can be divided in two categories, namely regression methods and time series estimation methods. A third category can be described as combining these two. Relevant forecasting techniques examples which belong to previous research studies are presented in the following paragraphs. The type of traffic data that was used along with possible inconveniences that we detected is included.

(Hobeika and Kim, 1994) constructed three models for short-term traffic prediction by combining the current traffic, the average historical data and the upstream traffic. (Li and McDonald, 2002) use GPS equipped probe vehicles and determine mean speed values in order to develop a fuzzy mathematical travel time estimation model. Time series analysis is as well a popular method to infer the travel time prediction due to their strong potential for on-line implementation. (Ishak et al., 2002) describe a short-term prediction model for speed that follows a nonlinear time series approach and uses a single variable.

In review of literature, researchers have used parametric models in order to forecast the travel time, such as regression models or time series and nonparametric models that include ANN models (Yu et al., 2008), (Lint et al. 2005). Studies have shown that Ann’s (including modular neural network model and state space neural network model) is a powerful tool to predict travel time on freeways (Lint et al., 2005). (Yu et. al., 2008) proposed a travel time prediction model which comprised two parts: a base travel time and a travel time variation. The first term is computed using a fuzzy membership value average of the clustered historical data that reflects the traffic pattern. The variation is predicted through a cluster based ANN in order to capture the traffic fluctuation.

3 DATA

Historical data may consist of single vehicles trajectories or it may be in the form of databases of traffic variables measurements recorded at spots on the roadways. The broadcasters along the roadways identify and report the travelling speed of vehicles at fixed time intervals, the number of vehicles or the congestion level. But most of the traffic measurements infer the travelling speed, which is most important for detecting the travelling time.

The raw data is processed in order to obtain traffic indicators, such as the average speed or the congestion level on the roads at fixed intervals. Missing data is usually computed by interpolation from the surrounding data (if it does not exceed a certain interval). Other problems might come up at the analysis stage because if the recordings are not done for each lane there are differences between trucks (which have a different speed limit) and cars. An example of a travel time plot obtained from historical data on highway A9 on the 25th of March 2003 is given in Figure 4.

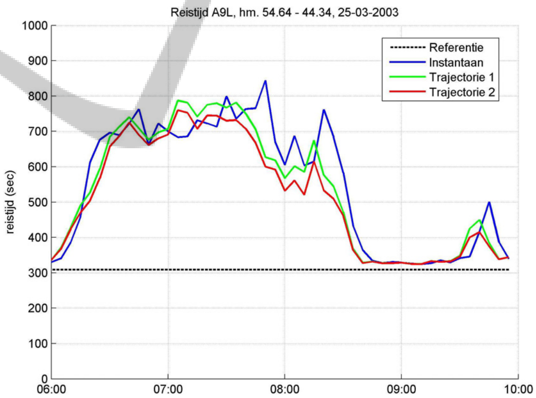

Figure 4: Dynamic route information.

Traffic data can be collected by a variety of data sensors, such as inductive loop detectors (ILD) (see Figure 5), videos, floating cars, remote traffic microware sensors etc. The latter represent a relatively new technology for collecting traffic data. But since it is still in the testing stage, only a limited number of such sensors have been installed in the United States. Therefore, it cannot be used for wide-area data collection.

ANWB is one of the services which attempts to offer a live traffic update for the highways network in The Netherlands. The application is using data from the monitoring system. It shows real life graphical information about the bottlenecks on the highway network by giving an estimate of the current average speeds (see Figure 6). This traffic information is available 24 hours a day on their website and is free of charge. The file that we used to fill in our database was built by collecting data from the ANWB website. The traffic data was collected each 10 minutes for a couple of weeks for a roadway network that comprised the highways and a few national roads from the country. For each road the traveling time was extracted from the text files that are offered by ANWB. All data was organized in an Excel file.

For each road the following information was stored:

- name of the road (such as A1, A2, etc.);
- names of the intersections bounding the road;
- length of the road in kilometers;
- maximum speed allowed on the road;
- associated travelling time computed based on the maximum speed;

starting from 0:00 to 23:50 for each 10 minutes interval the added travelling time in case of congestion.

The missing data in some cases was computed by interpolation from the surrounding data. After the processing and analysis of the collected data, 4 Thursdays were chosen in order to be further used. The file in Excel needed further processing in order to be integrated in our application.

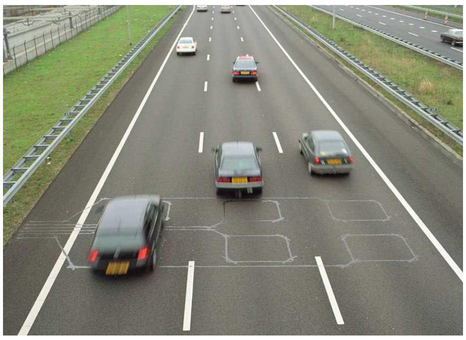

Figure 5: Wires in the surface of the road.

3.1 Open Source Tools

OpenStreetMap (OSM) is a collaborative project to create a free editable map of the world. OSM follows a similar concept as Wikipedia does, but for maps and other geographical facts. An important fact is that the OSM data does not resume to streets and roads. Anybody can gather location data across the globe from a variety of sources such as recordings from GPS devices, from free satellite imagery or simply from knowing an area very well, for example because they live there. This information then gets uploaded to OSM's central database from where it can be further modified, corrected and enriched by anyone who notices missing facts or errors about the area. OSM creates and provides free geographic data such as street maps to anyone who wants to use them. The OSM project was started because most maps that people think of as free actually have legal or technical restrictions on their use, holding back people from using them in creative, productive, or unexpected ways. Libraries to access the resources provided by the project are available for multiple languages and purposes. As an example, several rendering libraries exist (in Javascript, Python, C and Java) and also several editing clients that allow to interact with the data. In order to implement the graphical user interface of the system and to construct an initial database out of intersections and highways from The Netherlands, we embedded an OpenStreetMap map viewer in the application. This was a Java panel which allowed several listeners and functions to be redefined.

Figure 6: Dynamic route information.

Due to the modular design of Swing component library, the integration was an easy task.

The API of the OSM viewer provides a number of utilities for manipulating maps, allowing us to construct a robust user interface for our system. We were able to:

- create the intersections for the traffic network graph by clicking on the map.
- create directed links between two nodes - and we assume that all the roads are straight.
- calculate distances in kilometers between nodes by using their latitude and longitude.

• relate geographical coordinates to plane coordinates on the map.

• design (in different colours) paths on the map, parallel to the main roads in order to display a requested route.

An example of the OSM integrated in our application is presented in Figure 7. The intersections and the roads from the database are displayed on the map.

4 DYNAMIC DIJKSTRA TRAFFIC ASSIGNMENT

The starting point of the implementation for a dynamic traffic assignment is to build the traffic network as a time expanded graph. Given the traffic model that we presented in the previous section we need to implement the algorithm on a graph that is extended in time. This is determined by the time varying speed graphs, which we also presented in the previous chapter. Using this representation we can then apply known mathematical algorithms to solve our problem. As for general routing problems, the Dijkstra's shortest path algorithm could be applied. The main difference to a classic traffic assignment, in representing the network graph is that the cost varies in time.

The input to the algorithm is represented by a route request. A route request consists of an O-D (origin-destination) trip demand at a specific time. The algorithm will be applied on the network graph and it uses the nodes, the roads and the estimation of the travelling time based on the varying average speed associated to each road.

The network is represented by a graph $G = \{N,A\}$, where A is the set of directed links and N a set of nodes. G represents the spatial network, meaning the network of nodes and roads. In order to represent the dynamic travel time we will use a time extended network. The time expanded network can be constructed in the following way: the planning horizon is divided into variable time periods $\{t = 1,....T\}$ and each node is copied for each period t so that for each node k there are now T time-space nodes denoted kt. For each link j in the spatial network consider time-spaced links, $jt\tau$ joining the entry node of link j at each time t to the exit nodes of link j at latter times, $\tau = t + 1; t + 2,\ldots$. Thus for each spatial link we have time-expanded links $(jt\tau)$, $\tau = 1..T$, $t = 1....T$. This approach brings one constraint: the travel time has to be discretized to intervals. If we use a very high sample rate then an enormous graph is required whereas a lower sample rate results in loss of information.

Figure 7: Dynamic route information.

An example of a space time extended graph constructed in the modality that we just described is presented in Figure 8. The space graph represented by the nodes (A, B, C, D, E) is repeated for three time intervals (t1 at 09:00, t2 at 09:05 and t3 at 09:10). The edges that connect the nodes from A to E, coloured in red represent the initial connections in the graph. For clarity these edges were kept similar also for the other layers. But the edges in dotted lines are the real connections of the time expanded graph. They show the evolution in time of the speed flow along with the travelling time in the network. Their length, between the layers, represents the travelling time associated to the corresponding edge when starting at each layer. It should be noticed, however, that not all edges were represented in the Figure in order to keep it readable. For example, the travelling time from B to D is 5 minutes at 09:00 and 20 minutes at 09:05.

In order to show more clearly which are the differences between the DDTA and STA averages of the travelling time we use Table 1. In this table the first part shows the average time that DDTA gains compared to STA in minutes. Some values here may appear to be lower than expected but these are the averages. It is worth mentioning that in the worst case DDTA gives a result with the same travelling time as the other algorithms, but never worse. This is the case of the 0 values in the second part of the table. In this part we show at each hour the route with greatest gain in time for DDTA. We notice for example that from Rotterdam to Amsterdam we have a gain of 16.78 minutes at 8 o'clock.

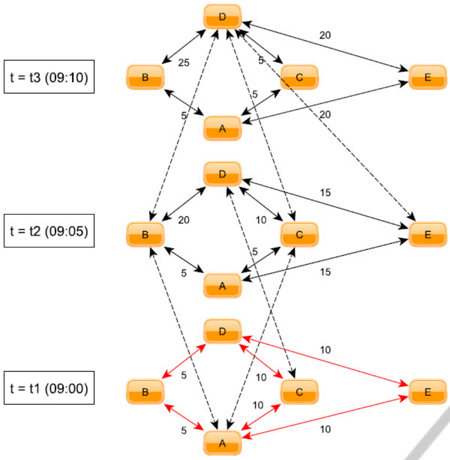

Figure 8: Dynamic route information.

5 MODEL

PTA gives the traveller routing advices during his trip starting from departure to destination. The traveller will benefit of the best available solution according to his preferences at the departure time. If unexpected events occur, it will result in modifications during the trip. PTA should distribute the traffic in the network so that it satisfies the preferences of the users by taking into account the availability in the network. The system will use continuously updated traffic flow information. This information would be available from the GPS-equipped mobile phones of the users. Given that the system knows which are the route requests and the routes assigned already to drivers it can give a prediction of the travelling times on the roads in the future. This can be done by training a neural network on the relation between various traffic parameters such as the traffic stream and the travelling time.

If we return to the individual routes assignment, in case of an incident/road work the system informs the traveller on the delays and best alternative solutions. The driver will be also informed on the travelling time associated to the recommended alternative, the types of roads and eventually the advantages/disadvantages. As we already mentioned, PTA connects to the users by a hand held device. This can be a smart phone, a routing device or a PDA.

PTA is a distributed system that links the users to the central server. All components are connected through Internet. Users are connected to the server but they can also communicate among themselves by using ad hoc wireless networks. A possibility to do this is by using the wireless network between light poles on the highways. In Table 1 we list the advantages and disadvantages of a distributed system.

Table 1: Dynamic Dijkstra Algorithm compared to Static Dijkstra Algorithm.

Average travel times difference (DDTA to SDA)								
		06:30	07:00	07:30	08:00	08:30	09:00	09:30
Amsterdam	Rotterdam	3,39	3,38	3,62	2,19	2,9	**6,57**	4,78
Rotterdam	Amsterdam	5,6	3,16	1,78	**10,04**	7,84	3,65	3,84
Eindhoven	Den Haag	4,7	3,29	1,87	2,7	4,03	4,8	**5,51**
Den Haag	Eindhoven	4,7	3,29	1,87	2,7	4,03	4,8	**5,51**
Eindhoven	Amsterdam	0,78	0,81	0,9	1,16	1,09	1,34	**1,75**
Amsterdam	Eindhoven	0,82	0,96	0,58	0,71	0,55	1,02	**1,22**
Utrecht	Amsterdam	0,84	0,51	1,25	1,25	0,65	**1,96**	1,14
Amsterdam	Utrecht	1,01	0,96	0,53	0,38	0,34	0,72	**1,82**
Amsterdam	Nijmegen	0	1,74	2,67	0,51	1,55	0,09	**3,24**
Nijmegen	Amsterdam	0,85	3,21	0,86	0,72	1,07	0	**1,36**
Maximum travel time difference when comparing DDTA to SDA								
		06:30	07:00	07:30	08:00	08:30	09:00	09:30
Amsterdam	Rotterdam	**12,55**	12,47	12,84	8,23	6,36	11,14	11,96
Rotterdam	Amsterdam	15,83	11,74	8,42	**16,73**	13,26	9,41	13,87
Eindhoven	Den Haag	**7,18**	6,22	4,6	2,85	4,86	5,76	5,51
Den Haag	Eindhoven	**7,18**	6,22	4,6	2,85	4,86	5,76	5,51
Eindhoven	Amsterdam	3,97	4,09	4,71	6,00	7,15	9,99	**10,96**
Amsterdam	Eindhoven	4,25	5,09	2,86	3,71	3,57	**6,8**	5,55
Utrecht	Amsterdam	4,53	2,4	5,97	6,05	3,56	**8,77**	7,15
Amsterdam	Utrecht	5,00	4,75	2,49	1,86	2,41	**5,06**	7,5
Amsterdam	Nijmegen	0	5,3	7,46	2,38	4,06	0,46	**9,42**
Nijmegen	Amsterdam	2,28	**8,12**	4,05	3,36	5,21	0,07	7,06

The advantage of PTA is that if the system becomes a centralized one (because of network problems) it still manages by connecting to the other cars in order to get the information it needs. Figure 9 depicts the architecture of PTA. The main server has to be connected to the roads and nodes database, to the historical database and to an incidents database. As we already mentioned, it is important for PTA to benefit of live traffic information. The system is designed in such a way that it uses the information from the vehicles that already exist in the network. The GPS-equipped mobile phones report their positions at fixed time intervals. Moreover, the routes of the vehicles are supervised, meaning that the system knows the origin, the destination and the departure time of each route. In this way the travelling time of the traffic flow in the future can be estimated.

6 CONCLUSIONS

As we mentioned in the introduction of this thesis, our main purpose was to build a dynamic traffic assignment. An important component of this is the prediction of the travelling time. In this paper we proposed a prediction method that would update the historical data based on supervising the routes in the network together with the real time traffic information.

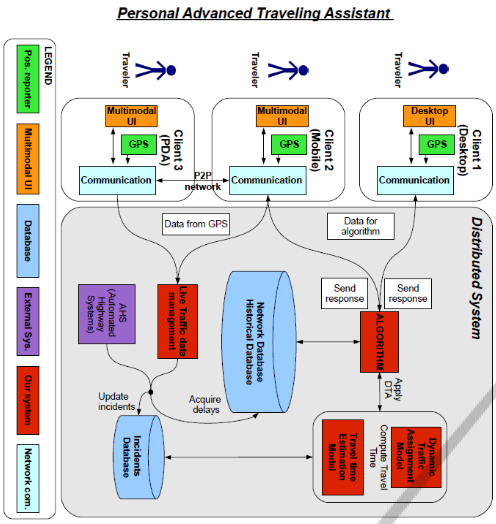

Figure 9: Dynamic route information.

Our prototype implements an algorithm that is a time dimensional extended version of Dijkstra shortest path algorithm. The main difference is that our algorithm takes into account the traffic variations in time. The cost function in the algorithm is associated with the travelling time. The algorithm uses the prediction model that we described previously. Because of the fact that the algorithm gives the route with the shortest time to each user we may categorize it as a user equilibrium assignment. However, we assume that just a part of the drivers in the network are connected to the system. If we deal with the whole network the situation would change.

The results of the algorithm were compared to the results of two variants of the static Dijkstra algorithm, one that computes the shortest path and one that uses the fastest roads given their maximum speed limit.

We developed a complex design for an advanced traveller information system that relies on the concept of distributed systems. The system that we designed integrates the use of live traffic information that derives from tracking the individuals and use of highway sensors. Travellers are routed through hand held devices which can be their mobile phones. Another important feature of the system that we designed is that it is usable by everybody, without any special training or knowledge needed. In order to get more insight into users' preferences with regard to such a system we did a user survey that mostly confirmed our expectations but also brought new ideas.

The system is also seen as a intelligent assistant as it has the capability to detect, learn the user's profile and associate it with his schedule. It combines this information with the traffic data and advises him about the best route to take.

Building the design of such a system was a challenging experience as there are numerous aspects to be taken into account. For each feature that we included in the design we also presented a possible manner to achieve it.

Given the huge complexity of the system we chose to implement the most important components with their basic characteristics.

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