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New ITS applications for metropolitan areas based on Floating Car Data

Introduction

Travel time is a main criterion for route choice in a road network, for private as well as for commercial users. However, travel times on metropolitan area roads are subject to strong fluctuations due to the variability of traffic demand and lots of interference like traffic lights.

Conventional stationary detectors observe traffic flow and local speed at certain locations of the road network and therefore are hardly able to provide reliable and area-wide travel time estimations.

An alternative approach is the use of floating car data (FCD). Experiences from three years of research in this technique are described in this paper. The activities also include the development of some prototypical mobility services based on FCD, which are described in the second part.

The collection and processing of Floating Car Data

FCD collection approaches

There are two approaches of how FCD can be collected: the *passive* and the *active* FCD approach.

Passive FCD extraction means "recognizing" a vehicle at one section of the road network and later on at another section, e.g. by automatic vehicle identification or passive onboard transponders responding on the signal of a stationary beacon. The time interval between the events allows an estimation of the average travel time between the two sections.

Active FCD extraction requires a positioning system (e.g. GPS) and a wireless communication unit onboard of the car. The position is transmitted at regular intervals or event driven to a data server. Here the positions are processed by applying a map matching and routing algorithm which assigns the positions to the segments given by a digital road map and calculates the travel time.

The idea of using cars as traffic sensors arose already in the 1980'th, getting a push with the advent of modern wireless communication technologies. However, both FCD extraction approaches are very costly in terms of hardware requirements as well as communication effort, what was the main obstacle for introducing this technique in a larger scale. This obstacle can be "bypassed" by using position data from commercial vehicle fleets.

FCD from commercial vehicle fleets

For the purpose of fleet monitoring and disposition some commercial vehicle fleets are already equipped with onboard positioning systems and communication devices for transmitting their current position frequently to a fleet management centre. Especially taxi companies are more and more using these systems, at least in Europe.

Over the last three years taxi companies from five European (Berlin, Munich, Nuremberg, Stuttgart, Vienna) and one Chinese city (Ningbo) supported this study by supplying taxi position data from about 5,000 taxis continuously and in real-time. About 200 million data sets have been recorded.

Processing Taxi FCD

The taxis are equipped with GPS receivers and communication units. They transmit their position periodically to the taxi centre. The transmission frequency depends on the status of the taxi (occupied, free, waiting, etc.), the average is about 40 seconds. This interval is in the range of 10 - 100 seconds which has been determined as the optimum transmission rate for FCD in [Gössel et al., 2003]. Each data record contains a taxi identity number, the time, the GPS position and the taxi status.

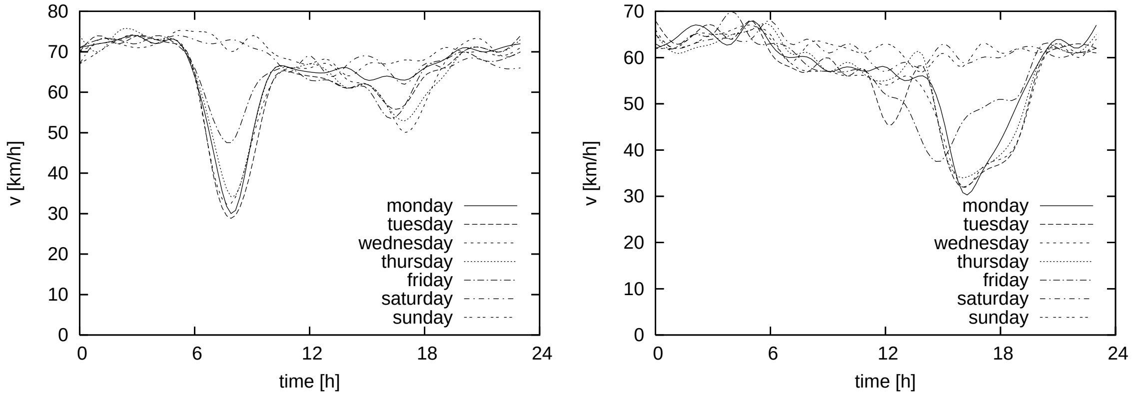
Processing taxi FCD starts with the elimination of not plausible (e.g. mismatched GPS positions) and not relevant (e.g. from taxis waiting for customers) data.

The second step is a map matching process where the position data are matched on a digital road map. (If such a map is not available there are ways to generate the main road network from the FCD themselves, see below). For this an algorithm was developed which combines this map matching process and the reconstruction of the routes driven by the taxis. By knowing the routes and the position records from the taxis the travel times on single road segments can be calculated.

On the one hand the calculated travel times can be used as an estimation of the current travel times, with an uncertainty growing fast by ageing of the data. Measurements not older than about 30 minutes can be used as estimations of the current travel times with sufficient accuracy.

On the other hand collecting FCD over a long time period gives a substantiated knowledge of the typical travel times and their daily course on the main roads of a city. A practical approach to condense these data is to derive diurnal courses of the travel time or the average speed for each road and each day of the week. In figure 1 the diurnal course of speed on the Cannstatter Strasse (Stuttgart) based on Taxi FCD is given.

Figure 1: Diurnal course of speed on Cannstatter Strasse, Stuttgart, by Taxi-FCD (left: into town, right: out of town)



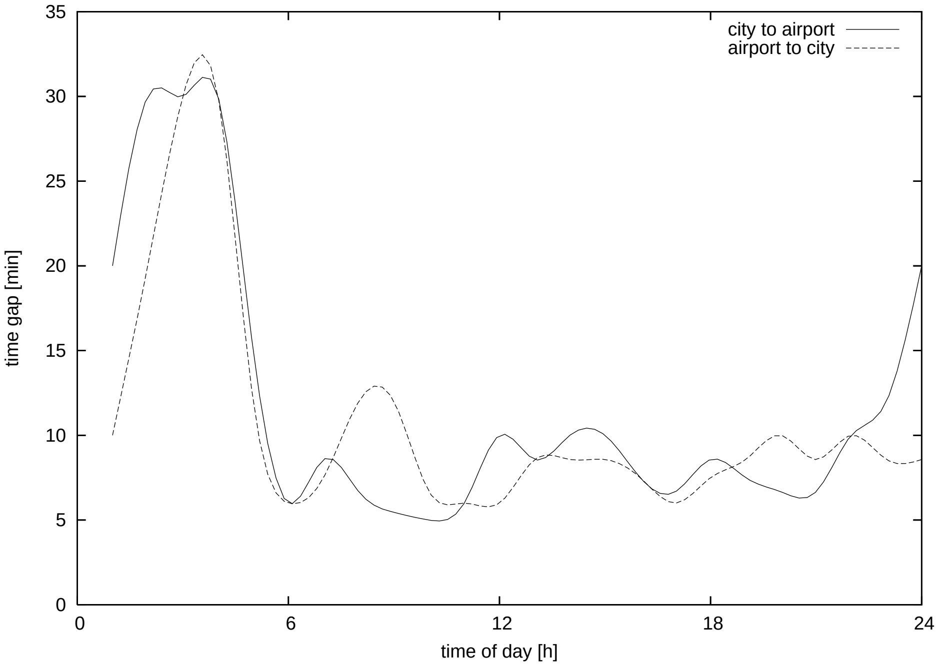
The morning rush hour on the way to the city and the evening rush hour on the way out of the city are clearly visible in figure 1. On Friday evening the rush hour velocity drop occurs more than one hour earlier in comparison to other working days.

Data coverage by Taxi FCD

The critical issue of a traffic monitoring system is given by its spatiotemporal data coverage. The data coverage reachable with Taxi FCD was analysed for the city area of Stuttgart. In this city nearly all (about 700) taxis are equipped with GPS receivers and deliver their position about once per minute to the taxi centre. The taxi density is given by about 800 inhabitants per taxi, which is a typical value for a German city.

A reliable real-time detection of traffic disturbances requires a high usage frequency of all very busy main roads by Floating Cars. Fortunately the usage of a road by taxis can be assumed to be more or less proportional to the total usage. High traffic volume roads with a corresponding high jam risk are consequently more often passed by a taxi then low traffic volume roads. For major roads of Stuttgart the usage frequency or, respectively, the average time gap between passing taxis was extracted. For the route between the airport and the city centre (main railway station) these average time gaps are shown in figure 2.

Figure 2: Average time gap between passing taxis on the route Stuttgart city - airport



On this route mean time gaps of 5 to 10 minutes are reached over the day hours, which correspond to the mean delay for detecting traffic disturbances on this route.

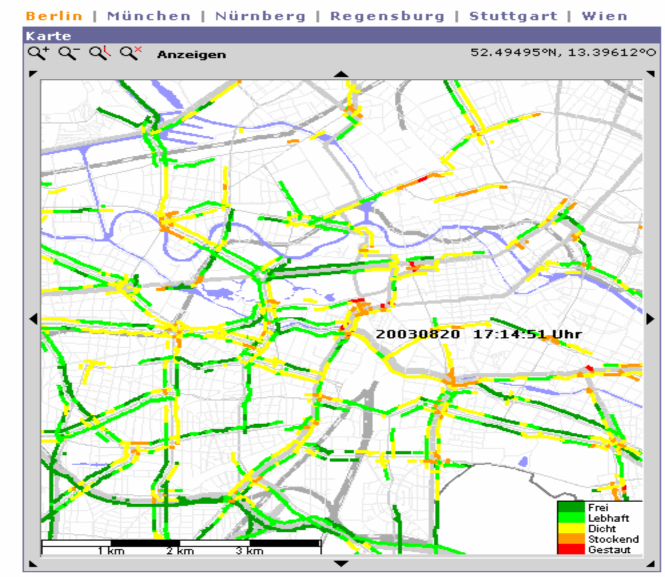
Analysing the FCD database shows an average fraction of taxi traffic on total road traffic in the investigated cities of 1 to 1.5%. This value is much higher during the night and decreases to about 0.7% during the morning peak hours. To provide data of an equivalent standard to roadside detectors (according to congestion detection) about 1% of the vehicles would be needed as probes [Chen, 2001]. Taxis do not always and everywhere reach this fraction. Nevertheless this taxi FCD penetration already allows the development and operation of the derived mobility services and applications presented below.

Applications arising from FCD systems

Traffic Monitoring

A basic mobility service is to inform the traveller about the current or a forecasted traffic situation. Therefore an internet information platform monitoring the travel times or the Level of Service (LOS) of the underlying road network was developed. It shows a map where the roads are coloured according to the ratio of their current passing time to the passing time arising from their speed limit (see Figure 3).

Figure 3: Traffic monitoring for Berlin city centre on 2003-20-08, evening rush hour



Automatic Congestion Detection

For non-graphical media like radio or teletext the current situation has to be filtered for congestions which are worth reporting.

Therefore, a congestion detection algorithm was implemented. The algorithm detects a congestion, if the travel time on a route exceeds the expected travel time by a significant factor (here: 50%) and by a significant amount (e.g. 10 min). The search can be limited to the higher-ranking road network. Compared to congestion reports given by travellers verbally e.g. to radio stations, the automatically generated congestion reports obtain a higher reliability and information content (e.g. passing time may be send along).

Dynamic Routing

The publication of the current traffic situation assists the traveller in his route selection. However, a major objective of Advanced Travellers Information Systems (ATIS) is to give route guidance to the traveller. Therefore navigation systems in terms of on-board or off-board devices have been developed and became popular.

However, most existing solutions doesn’t use real (current or historic) traffic data for routing, at least not in cities. Often, the expected travel time on a road is estimated using a static speed value based on the speed limit, which is very imprecise.

In this study the usage of traffic data collected by probe vehicles for route guidance was investigated. Therefore a web server was developed which supports route planning based on current and historical FCD.

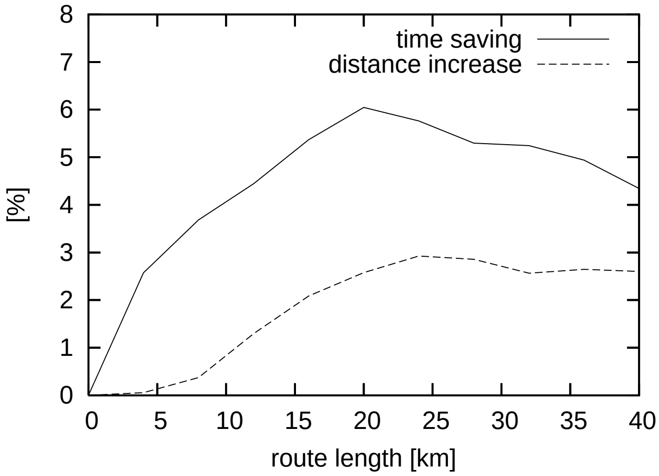
A wide range of factors influences the route choices of individuals. However, the most important factors are travel time and distance. For routing, a Dijkstra algorithm was implemented using travel time and/or distance-weighting factors for optimising the cost function. These factors are selectable by the user and express his willingness to drive longer routes for saving time.

Besides travel time and distance the variability of travel times is a further route selection criterion for travellers. Often constraints exist on arrival time at destination (e.g. reaching a flight at the airport). In these situations a traveller may prefer a route with a slightly longer, but more reliably estimated travel time. FCD is a suitable source for travel times as well as for their variability. As a next step a corresponding term will be added to the cost function.

The advantage of dynamic routing based on FCD was evaluated as follows: for several thousand randomly selected origin destination pairs in Vienna the fastest routes were calculated using taxi FCD and using static data (speed categories from Navteq Corp.) respectively. For about 80% of the pairs the routes differed. The expected travel times along the routes were calculated based on FCD. For the FCD based routes the travel times were in average 4-5%

less then on the routes calculated without FCD, and the distances were on an average 2% longer. Figure 4 shows the travel time saving and the distance increase as a function of the route length.

Figure 4: FCD-based routing vs. static routing



The web server mentioned above is accessible online via www.cityrouter.net. For mobile devices like PDAs and Java-enabled phones a Java application is downloadable from this site. A WAP version can be accessed via www.cityrouter.net/wap.

Off-board Navigation

As mentioned above, dynamic routing based on FCD can be made accessible from mobile devices like PDA's in a straightforward way via mobile internet (e.g. GPRS). Furthermore these devices can easily be enabled to determine their own position, normally by a adding a GPS receiver. By combining dynamic route information and the knowledge of the current position a navigation system can be developed.

In the context of this study a prototype of an off-board navigation system using FCD was implemented. Both visual as well as acoustic route guidance is offered by the system. Since the route is calculated on the server side, little computing power is needed on the PDA side. Furthermore the digital road map is needed only on server side, which simplifies the updating procedure.

Fleet disposition

It is difficult to develop a sustainable business model for above described applications for private user because of their low willingness to pay for mobility services. However, for commercial operators of vehicle fleets (e.g. suppliers, transport companies) the situation is different. Here the savings in travel time by dynamic routing can directly increase the fleet utilization and by this raise the companies profit. Therefore the willingness to pay for up to date travel time information and dynamic routing by commercial users is given in principal.

To test dynamic routing in the field of fleet management a prototype of a fleet disposition system has been developed, which uses taxi FCD based travel time information to optimise the operational planning. In frame of a field trial the system is in use for one year now at a Berlin limousine service (about 5 vehicles). The cars are equipped with PDAs which serve as navigation system, to transmit the orders to the drivers as well as for fleet monitoring and control of the order handling from the fleet management centre. The position is determined by GPS, and mobile internet (GPRS) is used for communication. The availability of GPRS in the Berlin area has proved as sufficient, but as fallback system SMS communication was implemented in the application. The communication costs were less than 20 € per month and car.

Creation of Digital Road Maps

Wherever vehicle navigation, route guidance or a microscopic traffic simulation is used it relies on digital road maps. Additionally, infrastructure assessments and GIS-based analysis often require a digital representation of the road network.

At present, nearly complete West-European and North-American road nets are available as digital maps. But the coverage of other regions in the world is still very patchy. Also the maps might become inaccurate quite fast, especially in regions with rapidly changing infrastructure, and it is therefore a special challenge to keep them updated. Standard procedures to produce digitized road maps are very expensive and time consuming.

We propose a new methodology to derive digital road maps and street characteristics from ordinary taxi-FCD. First of all, the raw GPS data is filtered to eliminate improper data. To allow the application of statistical methods, the data is transformed to GPS hit density per unit square for the region of interest. Further on, filtering algorithms exploiting local statistics [Lee 1986] are used for padding and denoising. To derive basic street objects, a thinning algorithm was applied [Pavlidis 1982]. This procedure leads to a skeleton of the street network. For simplicity, the vectorized objects are composed of linear segments. Therefore, linear fitting is iteratively performed by minimizing the chi-square error statistic and resampling the objects toward a convergence criterion. The post processing steps are rule-based algorithms to correct the obtained digital maps. Depending on user needs, it can include edge and knot merging, connecting to nearest knots or edges, shortening or even deleting of implausible segments. An example of an automatic FCD-based road generation for a test area of approximately 6x6 km^2 in the city centre of Berlin is shown in Figure 5a. For comparison, Figure 5b shows the same area in a commercial digital map. As seen in these figures, the overall structure of the city road network is completely recovered by our method. All major roads can be identified, whereas various minor routes are only partly recognised because of low data penetration. Beside the road network topography a number of street attributes can be derived. In Figure 3a the identified multi-lane segments of the test area are marked with thicker lines.

Although the quality of the obtained results cannot compete with the standard techniques, the method has several advantages. Wherever GPS data from vehicles is available, a low-cost map can be produced just in time. It is especially well suited for error recognition within maps and to supplement expensive updating procedures of already existing digital road maps.

Figure 5: a) Automatically generated digital road map of Berlin city centre, thick lines indicate recognised multi-lane roads, b) Same area, NAVTEQ® road network

a

b

Conclusions

The paper described a couple of FCD based vehicular traffic applications and services. This new method is especially beneficial for regions with a poor traffic monitoring infrastructure because the necessary monetary effort to establish such a system is very small in comparison to conventional systems and it is flexible and easily adaptable to other regions. Particularly, emerging markets like China with a fast-changing road network and a high penetration of latest information technologies on one side but with serious foreseeable traffic related problems on the other side can surely profit from this approach.

The new data collection and analysing methods result in better performance of the services enhance the scope of the services and hopefully enlarge user acceptance. All of the proposed solutions are prototypes and not all of them have been extensively tested up to now. Certainly, specific data processing methods need further research, some refinements and calibrations. Additionally, some applications still suffer from insufficient data penetration. Nevertheless, the approach is very general and it is very likely that FCD availability will sharply increase in near future and will enhance the quality of services.

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