The Concept of an Intelligent Road

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Abstract: This paper shows the potentials of the Floating Car Data (FCD) method for a typical highway system and the challenges for the road design. It describes how the highway system can be used more certainly and more efficiently, above all, in view of the increasing number of automobiles. To do justice to all circumstances and challenges the Floating Car Data method and a driving assistance system, supported by a multi sensor technology (navigation, road guidance and stabilizing) must be tuned to each other to be able to develop an "intelligent road". The concept of an intelligent road was coined a few years ago and is gaining momentum. The basic idea behind an intelligent road system is to enable a three-way communication among the road (sometimes called the infrastructure), the vehicle, and the driver. We examine the concept of an intelligent road in this paper and also discuss the traffic-flow behavior along the so-called intelligent road.

Key-Words: floating car data, intelligent road, global positioning system, traffic flow

1 Introduction

New Intelligent Transportation System (ITS) technologies if fully exploited hold greater promise for addressing critical transportation issues, such as safety, mobility, and infrastructure deterioration. Intersection and roadway accidents are caused due to many factors, such as roadway geometry, vehicle characteristics, and driver and pedestrian errors. Limited studies have been reported in studying a unified three pronged approach to understand the interaction among the vehicle, roadway, and human behavior and analyze the multiobjective trade-off opportunities to understand the “accident making” situations due to the complex interrelationships of roadway, vehicle, and human characteristics. Recurrent congestions are frequent on urban roads, which result in billions of dollars in lost travel-time and contribute to accidents. The traditional ITS technologies have primarily relied on loop detector data as well as real-time surveillance of critical roadway segments through close-circuit TVs (CCTVs), so that timely reconnaissance measures can be taken in the event of accidents, to improve mobility in rush hour.

The concept of probe vehicles to obtain real-time data such as traffic volume, speed, and density has been introduced in recent years [1]. Some research has been done to use the cell-phone enabled GPS (Global Positioning System) technology for collecting real-time traffic data [2]. To a large extent, traffic control and traffic information services depend on accurate information about the situation on the road network. Often rough estimates of queue lengths [1] are no longer sufficient to give a reasonable prediction of travel times. Traditionally the situation on the road network is derived from local measurements (e.g. induction loops). It is difficult to obtain travel time estimates from local speed and flow data. It is especially difficult in urban areas. When the positions of a sufficient number of vehicles can be frequently communicated to a central site, travel times can be directly measured. This is called Floating Car Data (FCD).

Real-time floating car data capture, transmission, and processing by making an “intelligent road” which can interact with an “intelligent vehicle” can allow relaying real-time road condition (such as icy conditions along
certain part of a road) back to drivers riding in so called intelligent vehicles through a central “information transmitting station or provider.” Among many benefits, this technology can avoid massive traffic backups caused due to severe weather conditions where the pavement temperature is generally not known to the driver. The aforementioned idea is demonstrated through a diagram in Figure 1.

The following services can be provided to the driver with an improved service quality:

- local traffic jam warning with video pictures (tactical traffic information)
- in-vehicle display of prevailing roadway conditions
- recommendation to adapted speed - based on topical situation on the roads
- short-term travel season prediction, based on topical situation on the roads

The following services are designed for infrastructure operator:

- dynamic reaction to locally changing flow of traffic
- improved traffic management based on Floating Car Data
- security relevant information for drivers’ speed and distance suggestion

Figure 1. A Conceptual Diagram of an Intelligent Road

The objective of this paper is to summarize the advances made in the applications of FCD, introduce the concept of an intelligent road, and show the benefits of the intelligent road concept.

2 State-of-the-art in FCD

FCD is a relatively new concept [3-9], which has become popular in the last 10 years. From the measurement perspective FCD’s main advantage is the direct measurement of travel-time. This comes at a cost however. The travel-time is not known until the completion of a measurement-segment by a statistically sufficient number of vehicles. Where the measurement segment is the shortest stretch of road or time over which the travel-time is calculated. So, the measurement becomes available with a delay. This delay can be made relatively short, but is limited by a number of factors, such as:

- the accuracy of the vehicle positioning (in time and space)
- the communication speed (over GSM call-setup and network availability can be a serious limitation)
- the number of measurements on the measurement segment within a time-frame
• Obstacles on the measured road-segment (a major example is traffic controllers, with delays between zero and 120 seconds)

To get from the shortest measurement segment to segments of a length that is significant for traffic information or control, the travel times on the shorter segments must be added. In principle, larger segments can be built from short segments completed by different vehicles. The measurements on the individual segments must be sufficiently robust to be able to add them with confidence. Robustness here means that the measurements are representative for the possible speed on the segment. For this to be the case one would need multiple measurements on a segment as otherwise one would mistake a driver posting a letter for a driver stuck in a traffic jam. To get travel-times over an entire network, one needs recent measurements on all the segments in the network. This means that a relatively large percentage of the vehicles in the network must function as FCD-probes. Educated guesses talk about a few to ten percent of the total number of vehicles. A lower penetration of probe-vehicles will certainly imply that not all segments will have a recent measurement. Also at lower traffic densities the number of recent measurements will get lower. In the latter case the historic free-flow speed on that segment can be used. In summary:

• the travel-time data from FCD becomes available with a delay; this delay will get longer with a lower penetration of FCD-equipped vehicles
• combining short measurement-segments into larger significant segments can introduce errors
• a fairly large number of vehicles must be equipped as FCD-vehicles to get good network coverage
• FCD gives a direct measurement of the travel times in a network

Travel-time can also be inferred from speed and flow data by means of e.g. loop-detectors. The advantage here is that the measurements are instantaneous. Algorithms exist to calculate travel-time from the local speed and flow data. These algorithms work fairly well in a motorway environment. They are however very difficult to apply in the stop-and-go environment of an urban network.

3 Travel time prediction

Floating Car Data will give travel-time estimates of the current, or rather the recent past. For the planning of longer trips, it is necessary to have a prediction of the travel-times over the next 30 minutes to the next few hours. Current technology has not got a clear-cut solution for accurate predictions. Having available the more accurate estimates of the current situation, and especially the better historical data that FCD can provide, can be expected to improve the accuracy of prediction algorithms.

4 Applications

The travel-times determined by FCD can be used on many time-scales. They can be used on the tactical timescale (10-30 minutes) for traffic management, for instance in routing strategies. They can also be used on the planning timescale (months to years) to calculate very accurate Origin Destination matrices. The following sections describe some of the applications.

4.1 Basic Traffic Information

By using RDS-TMC locations in the output of the FCD-process, the travel-time information can be used in DATEX compliant Traffic Information Centre services. This data can be made available to the public in a number of ways:

• through standard radio traffic information
• as TMC messages for users with suitable Receivers
• through the Internet, for pre-trip planning. These types of services will either be free of charge or will carry a low price-tag for the user.

4.2 Advanced Traffic Information Services

The basic travel-time information can also be supplied in a personalized service to end-users as:

• personal pre-trip advice with modal choices
• personal route-advice during the trip
• as input to a navigation system

The medium for these services can be on-board telematics devices and navigation systems. New WAP (Wireless Access Protocol) capable GSM phones are another possibility for this kind of information. The advantage of a WAP-terminal is that it can be used pre-trip and in the various modes of transport. Advanced
traffic information services will normally be charged on a per-use basis.

### 4.3 Traffic Management

Having accurate estimates of travel-time in a network can be an excellent basis for the implementation of routing strategies. On motorways this can be implemented in a straightforward way on Variable Message Signs. Because there is a reliable travel-time available, drivers can be shown the travel-times on alternative routes to a certain destination, without the risk of undue skepticism of the part of the driver. The information can also be used indirectly to balance the load in a network. Actual travel-times can be compared to historical or free-flow travel-times. On this basis control can be adjusted, by directly influencing traffic control systems or indirectly by information to the users.

### 4.4 Logistics

Companies that have to schedule a number of trips a day to deliver goods, can improve their trip planning by having historical and real-time travel times of the total network they are using. FCD can provide historical travel-times in the network for different types of days. Characteristics like the day-of-the-week, the weather and holidays can be used to predict the travel-times at the trip-planning stage. The sequence of deliveries e.g. can be planned on basis of the travel-time optimum. Real time information can be used to adjust the prepared schedule.

### 4.5 Traffic Strategy Evaluation

When creating a new traffic strategy for an area, it is often difficult to evaluate the impact on traffic flows. Floating Car Data analysis can routinely collect the most important data for before and after studies.

### 4.6 Long Term Planning

For longer term planning purposes Origin Destination (OD) matrices are a valuable tool. Traditionally OD-matrices are compiled by counting traffic at strategic points in the network and then have a computer algorithm make an assignment of the most likely travel patterns fitting the counts. Sometimes these counts are improved upon by having video recordings of license numbers of cars, through which the assignment can be improved. Floating Car Data can improve the traditional methods significantly, especially when end-to-end, origin-to destination tracking of vehicles is done. Not only is there hard evidence for the assignment in the matrix, there is also timing data available.

### 4.7 FCD and Public Transport

As part of their normal operation, many public transport companies already track their vehicles through their networks. They do this to be able to prepare optimal schedules (optimal here often means: the lowest number of vehicles for a good/acceptable service-level to the customers). When the data of public-transport vehicles with trip-logging equipment is suitably filtered for the Occurrence of stops (on the negative side) and public transport priority at intersections or at special lanes (on the positive side), this data can be very useful as a source of travel-time information on the main routes in an urban network.

### 5 The Concept of an Intelligent Road

An intelligent road is the one that can transmit information back and forth to the driver, the vehicle, and the central station in the face of accidents and congestion. Intelligent roads enable drivers to make better informed decisions regarding trip routing during their normal travel patterns. Adjustments in routing may be attributed to driver familiarity with normal traffic conditions and the quantity of information available to driver at the critical decision points (see, Figure 2). Dynamic route planning can be improved thought the use of intelligent roads.

Intelligent Transportation Systems (ITS) have been able to collect traffic data and distribute them to transportation professionals and drivers over the web in an online environment. Traffic reporting organizations gather data from government funded remote sensors and provide it to journalists to insert as a byline while performing other duties. The distribution of traffic information, as it applies to real-time decision making, is often received too late to alter route decisions prior to a critical decision point.
Route assigning is a macroscopic view that proportions generated trips along roadway. Route choice depends upon free-flow travel time, volume, and capacity, which is used to estimate the severity of traffic congestion in relation to time. Models have been developed to estimate the relation between trip generation and route assigning, though many times these models are unable to predict for individual discrete choices.

Intelligent roads will provide drivers with discrete traffic information, in a simplistic form, that is exclusive to their individual needs. More often than not, drivers reach critical decisions point during route decision making without any data that contains relevant traffic densities. Though many drivers have GPS enabled phones and/or navigation systems, the use of these devices are not readily available as traffic data collectors. The commonality of these devices and their low cost when compared to ITS sensors make them ideal for real-time data collection and reliable benefits from the use of data.

6 Design of an Intelligent Road

Roadway planning and design is initiated by the need to move vehicles more efficiently, and/or improve driver safety. A typical highway design problem is to select an economical path to connect two destinations. Some numerical models used optimization and provided intelligence to roadway design while focusing on improving driver safety by reducing the number of accidents [10]. Such models are able to evaluate an existing condition and equate the net benefits achieved by proposed improvements. Ultimate driver safety is dependent on wide range of external and internal factors. Driver characteristics and how they interface with the roadway can be improved through the use of an intelligent road design.

Intelligent roads are designed to improve the information available to drivers which will improve their decision making capabilities. Remote sensing and cellular technologies offer the abilities to collect data, but the definition of the collection points are discrete in relation to an area transportation system. Understanding the spacing of critical decision points (Figure 2) should include the highway geometrics, qualitative traffic conditions, and an individual sense of the overall traffic flow.

6.1 Traffic Flow along an Intelligent Road

Traffic flow is a function of the density and the speed of a vehicle within a reference frame. A driver’s perception of the traffic flow conditions comes in the form of congestion. Modern intelligent traffic systems have provided drivers with travel conditions prior to beginning the trip, which may be long before they reach a critical decision point during their trip. In heavily congested areas, this information is often out-dated and results in a non-optimized decision in real-time.

Traffic flow models describe the predicted conditions based on the available information. The performance of the intelligent road design based traffic flow model is largely dependent on the condition of the information relied to the driver. Refined driver information, such as relaying a designated route, will greatly reduce the need for an increased driver processing rate. Giving unrefined information will increase safety concerns by adding to the 1011 bits/sec the driver is responsible for processing.

Traffic flow will not be directly improved by the use of intelligent road design or FCD, but is will improve the drivers’ ability to optimize their route planning.

7 Conclusions and Future Work

We hope to develop algorithms using the floating car data system to test the efficiency and traffic flow behavior of an intelligent road in some case study examples in our future works.

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