

An overview of in-vehicle route guidance system

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Abstract

In-vehicle route guidance systems have seen great development in recent years. They have become an important tool in alleviating congestion in the urban transportation network. As a result of the advantages associated with navigation techniques and popularized digital maps, in-vehicle guidance systems are both economical and useful. In-vehicle route guidance systems are being accepted by more and more users, in many countries and for these reasons, research has focussed on improving their performance.

The aim of this paper is to review related literature, classify and make a comparison among current advances in existing in-vehicle route guidance systems. Some of main components in the in-vehicle route guidance system and existing methods that have widely been proposed by researchers are investigated in detail. In face of significant research in this area, we point out certain work limitation, provide some comments, and also make suggestions for future work in this area.

1. Introduction

With the development of the economy, the need for transportation is growing at a rapid speed. In many countries, many roads are being built and in many places advanced traffic management methods are being used. It is beneficial for people to have multiple route choices instead of a single one. However, in some situations, building more roads is now less likely due to higher costs and less space, and may not always be desirable. For example, the Braess Paradox principle shows that adding a road may result in an increased total travel time (Braess et al 2005). In parallel to new roads, intelligent transportation system (ITS) technology has been developed in recent years to make the existing roadway networks more efficient.

ITS is a system that integrates many advanced technologies such as communication engineering, information theory and navigation principles, in order to make transportation systems reliable and efficient (Huang et al 1995). In the past twenty years, the field of ITS has grown rapidly. Traffic congestion continues to be a serious problem in modern society and ITS can be a very good way to ease this problem. Indeed, ITS provides various approaches to dealing with traffic congestion on road networks. Adler (2001) had shown how traffic advisory information and route guidance could decrease travel time for unfamiliar users. In-vehicle navigation systems which are an important part of ITS were initially used by a small proportion of people because these systems were expensive and mainly installed in high-priced cars. However, with the increasing demand for these goods and the cheaper cost of this system, the situation has changed and navigational systems have now become daily necessities to make travel easier (Kaparias 2008). Users start up the navigator and input the destination address according to multiple choices (post code, suburb, street or historical place), then the system determines the route for the users based on the electronic map, and using real-time information and/or historical data stored in the memory space, and current vehicle position with the help of Global Positioning System (GPS). Both visual and acoustic indicators can help users follow the suggested route.

First-generation navigation systems primarily select routes on the basis of the shortest distance between a source and a destination. Recently, new advanced systems are capable

of incorporating real-time congestion delays which allow the users to find the shortest travel time route instead of the standard shortest distance route, and enabling users to adapt to dynamic traffic conditions. The number of traffic sensors embedded in roadways for the collection of traffic speed, flow, and density has significantly increased in the past several years. In particular, major metropolitan areas in many countries have traffic sensors installed in their freeway networks, and they are continuously monitoring and recording traffic status. A good example of this is the California's Free-way Performance Measurement System (Choe et al. 2002) operated by the California Department of Transportation and the University of California, Berkeley. It is possible for users to monitor the traffic conditions and select routes based on real-time traffic conditions. Navigation systems also have the capability to reroute if a user deviates from the selected route or wishes to avoid a particular area of the roadway network. Skog and Handel (2009) presented a survey of information sources and information fusion technologies used in in-vehicle navigation systems and also briefly discussed common filter techniques to combine the information from different sources.

This paper is mainly based on broad existing literature and reviews different approaches for route guidance systems. The paper is organized as follows:

- Section 2 introduces an overview of historical development of in-vehicle navigation systems and two basic classifications of route guidance systems.
- Section 3 discusses travel time distribution, existing major reliability indices focusing on travel time reliability and travel time prediction models.
- Section 4 examines various simulation models that are specially designed for evaluating route guidance systems.
- Section 5 presents the application of algorithms to solve the route-search problem.
- Section 6 provides conclusions and suggestions for future work.

2. Overview of in-vehicle navigation

In this section, we review the previous work on in-vehicle navigation systems. We also sort and make a comparison among current advances in route guidance systems. A brief historical overview of in-vehicle navigation is first given in Section 2.1, which illustrates the development over many years. Section 2.2 presents state-of-the-art static and dynamic route guidance systems, including the description of the characters of these systems and a brief overview of the topic. While in the last subsection, we introduce decentralized and centralized route guidance systems, make a comparison and show the relevant research.

2.1 Brief historical review of navigation

The first in-vehicle navigation system appeared because wireless communication progressed significantly. In the 1960s, the US Federal Highway Association developed the Electronic Route Guidance System (ERGS), aiming to provide route guidance to vehicles (Kaparias 2008). An in-vehicle unit was used in this system to provide the interaction between users and the system. In the late 1970s, a dynamic route guidance system was developed in Japan. This system was based on FR (radio-frequency) communication methods and provided additional new route guidance functions. Test experiments were conducted on this system and the final results showed 13% of total travel time saving. After that, research on an AUTOGUIDE system was investigated in Germany and the UK, which used ultrared ray communication methods.

Since 1990, Global Positioning System (GPS) and Geographic Information System (GIS) technologies have progressed significantly and been widely used to improve navigation systems. These advances have made GPS receivers affordable and have led to comprehensive research in the field. In general, in-vehicle navigation systems rely on both latitude and altitude direction of current car position and match these with a digital map inside

the system. After inputting the destination node, the system will calculate a path for users to take and guide them to reach the destination point. Zhao (1997) described the basic components of navigation systems, which were composed of a communication module, digital map module, positioning module, map-matching module, route planning module and human machine interface module.

Navigation machines are now affordable consumer goods and are widely used in all kinds of vehicles to meet the increasing demand from users. Some leading providers of location and navigation solutions, such as Tomtom and Navman, have developed a range of high-performance products. These companies also provide a digital map service on the internet for mobile phones or personal digital assistants (PDAs). Hence people can use the service even when there is no navigation equipment at hand.

In the next subsection, some basic and important research points of route guidance system will be described.

2.2 Route guidance system

Recently, there has been a lot of research on route guidance and path finding, particularly investigating dynamic parts. Route guidance system (RGS) is generally believed to be an efficient way of alleviating traffic congestion, enhancing the performance of road networks, and also provides navigational assistance to users who are unfamiliar with a road network, and thus improves their decision-making. Similarly, a substantial number of studies have been conducted to model users' behaviours under Advanced Traveller Information Systems (ATIS), a well-known RGS. Studies have also evaluated the system benefits achieved by ATIS, assuming various level of market penetration of ATIS (Yang 1999).

The main purpose of the routing part in the navigation system is to compute the shortest or minimum travel time route, after users have input details about a destination node. RGS can be classified as a static and dynamic system. This classification is determined by ascertaining whether vehicles can receive real-time information and react to this information in the corresponding transportation network.

Static routing methods compute a fixed path between the original and destination nodes for users. Users do not receive and respond to any useful real-time information along the route. Several related studies have been conducted in this area. These papers explore the shortest route issues and propose relevant algorithms, such as Dijkstra's algorithm (Dijkstra 1959), Bellman-Ford algorithm (Bellman 1958), A* heuristic algorithm (Hart et al 1968) and bi-directional algorithm (Nicholson 1966). For a more detailed study of these algorithms, please refer to Kaparias (2008). However, some of these algorithms cannot be used to solve the shortest path problem under the time-dependent constraint. Static routing algorithms find it hard to determine the optimal route, without real-time traffic information because the traffic condition is continuously changing.

To this end, under intelligent transportation systems, the dynamic route guidance system (DRGS) has received wide attention. This system can provide routing suggestions to users in accordance with current traffic conditions that is a viable solution for the above problems. The information providing mechanism is decided by the current position of users, the availability of information and the destination node. This kind of routing method provides an optimal solution for users, and results in less traffic congestion. For example, Zou et al (2007) used an intuitive encoding scheme to solve the shortest path problem in dynamic networks that did not satisfy the FIFO (first-in-first-out) property. Experimental results demonstrated the advantage of genetic algorithm in a very large scale dynamic optimization problem. Yoo et al (2005) introduced the location-based dynamic route guidance system developed by Korea Highway Cooperation (KHC). The target users of this system were mobile-phone users in Korea. This research showed how to use real-time and historical profiles in order to predict link travel time for future periods. Wu et al (2008) used a new dynamic traffic model (DTM) to characterize the routing choice behaviours of users effected

by traffic congestion, in addition road grades were considered for different underlying network topologies. Comparing this with the random network, the scale-free network could bear a larger capacity of traffic flow. This model is considered suitable to design and to manage the urban traffic network.

Consequently, the difference between static and dynamic route guidance systems is clear. The static route guidance system is easy to implement and requires little computation time, but it does not work well when there is unexpected event happens such as an accident or in a heavy congested network. Dynamic route guidance can receive real-time information and avoid congestion situations at the cost of computation complexity. With the advances in wireless sensor technology, computing equipment, communication systems, other supporting systems and cheaper information access charges, the demand for real-time navigation systems will increase gradually, and dynamic route guidance system becomes a norm.

2.3 Decentralized and centralized dynamic routing system

The usual classification for the dynamic route guidance system includes both a centralized and decentralized system. Both centralized and decentralized systems can provide dynamic routing decisions. The main difference is that the former exchanges information between a vehicle and an information centre, providing more reliable and accurate information at the overall level; while the latter is based on estimated link travel time to make route decisions and is operated within the vehicle unit.

Several published works investigate centralized route guidance system architecture, e.g. Cameron et al (1983) discussed Northern Telecom's dynamic alternative routing system, which was a centralized routing system and selected routes based on probabilities. In another study by Hawas and Mahmassani (1996), they examined a method to provide real-time route guidance in congested road networks. The study was conducted as system-optimal logic in a centralized architecture.

As to the decentralized systems, Minciardi and Gaetani (2001) investigated a feedback decentralized optimal traffic control method in urban network. A decentralized route guidance algorithm was proposed by Farver and Chabini (2003) in a later study. This algorithm responded to small amounts of network stochastic, as well as the congestion effect caused by incidents. However, centralised systems are the most usual systems that are installed in vehicles today and are superior in the whole network level to the decentralized systems.

3. Travel time variable and prediction

In this section, we review previous works focusing on travel time analysis. Initially, two kinds of classical travel time distribution are described in detail. Then three major existing reliability indices are discussed. Travel time reliability, which is a significant performance metric for transportation networks, is then examined in detail. After that, the travel time prediction model is presented, including those most widely used, as well as their modifications by different methods.

3.1 Travel time distribution

The distribution of travel time is a significant issue when considering travel time variability and reliability. Before illustrating the existing method on modelling travel time reliability, we will investigate the travel time distribution. A large number of studies have been focussed on this topic in the recent decades. Generally we can divide them into two parts - discrete and continuous probability distributions.

Travel time is a random variable with many discrete values and corresponding probabilities in discrete travel time distribution. Gao (2004) solved the optimal routing policy problem in a stochastic time-dependent network, where link travel time at each time interval was modelled as random variables, with a finite number of discrete, positive and integral support points.

However, when deploying the algorithm proposed for optimal route discovery, full knowledge of this probable distribution was an unrealistic assumption, and the computation time was generally exponential in the number of arcs and support points. Accordingly, approximation methods were proposed (Gao and Chabini 2006) and a comparison among these was undertaken, both theoretically and computationally.

Compared to discrete distribution, continuous travel time distribution gains more focus in the literature. Wardrop (1952) first pointed out that travel time followed a right-skewed distribution. Later studies confirmed that the actual travel time distributions were similar to gamma or log-normal distribution. For instance, in a study on estimating path travel time reliability by Rakha et al (2006), travel times were assumed to follow normal distribution. However, Automatic Vehicle Identification data was analysed in this study and concluded that log-normal distribution was a more appropriate presentation of roadway travel times than normal distribution. Kaparias (2008) proposed two travel time reliability indices as lateness and earliness for examining reliable route finding methods. This study assumed that travel time followed log-normal distribution. Based on mean travel time and its variance value, reliability data could be calculated from historical continuous travel time distribution. While classical study assumed log-normal distribution as the best fitting estimation, in the later study by Susilawati (2009), actual travel time distribution was found to be bimodal, based on substantial data analysis conducted in Adelaide, Australia. Therefore, it is evident that travel time distribution format is an important factor to be considered before investigating reliability indices.

3.2 Existing reliability indices

Minimum travel time is the first-line consideration of users when making route decisions. However, in reality, when faced with uncertainty such as natural disasters, traffic incidents and congestion, which result in increased road use of certain routes, users are also concerned about whether expected travel time is reliable.

Up to now there are three major existing reliability indices for modelling traffic network performance: connectivity reliability, travel time reliability and capacity reliability. Connectivity reliability is defined as the probability that there is at least one path without heavy delay from the route origin to the destination, in a time interval (Yasunori 1999). This definition is concerned with the probability that the network nodes remain connected (Chen et al 1999). Travel time reliability is related to the probability of the trip between an O-D pair reaching a destination within a certain travel time. Many researchers have pointed out the importance of considering travel time reliability (Kaparias 2008, Gao 2004, Rakha et al 2006) and making the suggested route reliable for the travellers to take. Furthermore, capacity reliability of the traffic network stands for the probability that the network capacity can agree with certain demand levels. In a recent study by Kuang et al (2008), road capacity reliability based on O-D pair travel time reliability was conducted because these two indices are interdependent in a given network. However, the above three reliability measures mainly focused on either demand or supply uncertainty, which are the main reasons why travel time is uncertain. Little attention has been paid to the investigation of traffic network performance measures, with both demand and supply uncertainties. To meet this requirement, travel time variance caused by both demand and supply fluctuations, were studied by Hu et al (2008).

The different reliability indices mentioned above can be used to consider the varying impact of the reliability evaluation of transportation networks. However, among these indices, travel time reliability is the most widely used in the in-vehicle route guidance system. Many research studies have pointed out the importance of including travel time reliability, and related models that incorporate reliability metric and quantify the reliability. An early study using travel time distribution to calculate the reliability of link was shown by Polus (1979), where the reliability was defined as the inverse of the standard deviation of the travel time distribution under the assumption that travel time followed the gamma distribution. A study by

Lam and Small (2001) concluded that reliability was a significant factor in route choice. The data was analysed to show the differing preferences between men and women.

Research work has also been conducted, which focuses on modelling travel time reliability. A literature review of this topic was provided in Bates et al (2001). In a later study, Lint et al (2005) defined two travel time reliability indices, including the skewness and width of travel time, which was a ratio of the difference under different percentages of travel time. Kaparias (2008) introduced two reliability indices according to the log, normal travel time distribution, earliness and lateness, respectively. Both indices reflected the deviation to the mean travel time value.

3.3 Travel time prediction method

Travel time refers to the time spent travelling along a link or path. Basically, there are three different kinds of data formats - historical, current and predictive travel time data (Chrobok et al 2000). Travel time data is very important for the route guidance system and for users to make decisions. Based on accurate travel time prediction, users can change their departure time and select the route that has the optimal expected arrival time. As to the in-vehicle route guidance system, it can benefit from accurate travel time prediction technologies, provide alternative route for travellers and avoid potential congestion areas. From the traffic management point of view, it is better to evaluate the total performance of traffic network.

A significant amount of research has been conducted into the travel time prediction system. The travel time prediction model can be divided into two types: the analytical model and the statistical model (Wu et al 2004). The analytical model uses the macroscopic or microscopic traffic simulator method to predict travel time, like MITSIM by Yang and Haris (1996), METANET by Kotsialos et al (2002), and THOREAU by Codelli et al (1992). In comparison the statistical model takes historical and current travel time and speed data, as the inputs. It is possible to predict the future arrival time based on historical travel time data up to the current time. Significant work on travel time prediction has been conducted in the light of the statistical model proposed (Rice and Van 2004, Li 2002, Van et al 2000). Wu et al (2004) applied the support vector regression method for travel time prediction. Compared with other baseline methods using real highway data in Taiwan, they showed that their method was feasible and applicable for traffic data analysis.

Another important body of research focuses on the Artificial Intelligence (AI) method, such as neural network and neuro-fuzzy models. A detailed review of travel time prediction in the transportation area can be seen in Lin et al (2005).

Intelligent transport systems provide various means to improve traffic congestion in traffic networks. ATIS is a significant sub-system of ITS and can provide users with up-to-date network information. Based on this information, users can make a better decision and try to avoid the congestion area. Variable message signs (VMSs) are one of the most common information sources in short-term predictions of travel time on freeways. Zhang and John (2003) proposed a method to predict short-term freeway trip travel time based on a time varying factor linear model with freeway sensor data; a similar linear model was also applied by Kwon et al (2000). Van (2008) proposed a new online learning method based on the extended Kalman filter (EKF) for freeway travel time prediction. It was the first time the literature dealt with travel time prediction problems with the online learning method.

It is obvious that the research discussed above is significant in analysing travel time characters. The following section will summarize the main contributions in the simulation model undertaken by a number of researchers.

4. Simulation model

In recent years, some traffic simulation models and tools that are specially designed for evaluating route guidance systems have been developed. One of the traffic simulation

softwares, Simulation of Urban MObility (SUMO) traffic model is proposed by the Institute of Transportation Research (IVF) in German Aerospace Centre. It is a microscopic, multi-modal, space continuous and time discrete traffic simulation tool which has been widely used by many researchers. The SUMO package allows users to explicitly define routes and provides a common platform to test models. Moshe et al (1997) presented DynaMIT software system models for real-time guidance based on predictive traffic conditions in traffic information centre. Network state estimation and prediction-based guidance generation were two main parts of this system. DynaMIT interacted with the traffic surveillance system and generated user-optimal guidance which took into account estimated network conditions and traveller response to information.

In respect of simulation model, Yang and Haris (1996) developed an advanced microscopic traffic simulator MITSIM (Microscopic Traffic Simulator) to simulate traffic networks and to reflect driver reactions to information. Different models were implemented in this system to evaluate dynamic traffic system. Based on the real-time traffic information, route choice was made according to probability model. Yang et al (2000) also presented a simulation-based laboratory environment, MITSIMLab, which included microscopic traffic simulator (MITSIM), traffic management simulator (TMS) and traffic prediction function in a laboratory environment. This system provided all the functionality needed for the evaluation of dynamic traffic management systems which other similar models cannot achieve. Sen and Thakuriah (1995) described a specific system called Advanced Driver and Vehicle Advisory Navigation Concept (ADVANCE) which was a large-scale ATIS with dynamic route guidance capability and was deployed in a suburban area of Chicago.

Hidas (2002) proposed a Simulation of Intelligent Transport Systems (SITRAS), a microscopic simulation system in which the general ITS evaluation tool was developed. Algorithms and simulation examples were presented to evaluate the effect of enforced models and focused on the lane changing or merging. Codelli et al. (1992) also put forward the THOREAU simulation model, which was a microscopic model developed for evaluation. However, the main drawbacks were that it had a very long running time in practical. Examples for macroscopic models were Jayakrishnan et al (1994) and Aerde and Yagar (1988) which were designed mainly for dynamic traffic assignment applications.

5. Algorithm

In this section, the routing algorithms including basic and real-time routing procedures will be described in detail, together with computational impacts.

5.1 Basic routing algorithm

To solve the route search problem, routing algorithms can be classified into two categories. On one hand, the routing algorithm which searches on both the grid and graph can find the shortest path as long as the path exists. However, the algorithm itself has an inherent long running time when it works. Dijkstra (1959) proposed Dijkstra's algorithm, which was a graph search algorithm that solved the single-source shortest path problem for a graph with nonnegative edge path costs. Lee (2006) provided a modified Dijkstra algorithm applying in the vehicle guidance system. Generally, in this category, vehicle route guidance algorithms can be divided into two kinds: shortest path algorithm and fastest path algorithm (Chen et al 2009). The shortest path algorithms focus on route length parameter and find the shortest route between each OD pair, while the fastest path algorithm calculates the path with minimum travel time. Link travel time information can be obtained from historical data during a day, a week or a season and can be used to predict the future travel time by means of prediction models. On the other hand, some researchers use meta-heuristics to find a sub-optimal solution within a short time. Yoshikawa and Terai (2009) used hybrid genetic algorithm to solve this simple issue. In Yoshikawa and Otani (2010), the authors proposed a new hybrid routing algorithm which combined Tabu search with Ant Colony Optimization (ACO). It was able to find the shortest route when the blind alley existed in the map. Heuristic

shortest path algorithm is applicable for transportation situation which requires either quick response or repeated calculation. More studies aiming to design different kinds of heuristic shortest path algorithms are in the literature. A comprehensive summary of various heuristic shortest path algorithms that have been developed in the past can be seen in Fu et al (2006).

5.2 Real-time routing algorithm

There are four common situations and models relating to link travel time in the literature, such as constant link travel time, time-dependent link travel time, stochastic link travel time and stochastic time-dependent link travel time.

The most basic model assumes the link travel time is constant, which is deterministic or deterministic time dependent (different time intervals have different link travel time). In reality, the more common situation is that link travel time is stochastic with time-dependent character. The standard shortest path algorithm may not find the shortest path in the whole traffic network in this situation. For instance, Fu (2001) studied an adaptive routing algorithm for an in-vehicle navigation system with real-time information. The link travel time was modelled as a random variable with known mean and standard deviation. Travel time realization was estimated based on real-time data and an optimal adaptive algorithm was applied to select the route. The optimal routing policy problems in stochastic time-dependent networks were thoroughly investigated by Gao and Chabini (2006). A prior joint distribution of all link travel time data was assumed to be available to users. At each decision node, according to the real-time travel time information, the minimum expected travel time route can be decided by using the proposed algorithm.

Wang et al (2006) investigated real-time route guidance in large-scale express ring roads focusing on feedback routing performance, in case of incidents. Real-time dynamic user equilibrium (DUE) was established within the freeway network by suggesting alternative routes to users, in order that no users who followed route suggestions were disadvantaged in travel time, as compared to non-followers.

Ding et al (2010) introduced the main component of the real-time route guidance system and related work, in two different approaches to collecting real-time traffic information; vehicle-to-roadside communication and vehicle-to-vehicle communication, respectively. The main focus of this work was employing vehicle-to-vehicle communication to develop a real-time vehicle route guidance algorithm, which consisted of two parts: a smart route query and reply strategy of route finding algorithm (using flooding strategy to find out all potential routes that take less time than the shortest path), and also a detour algorithm in order to bypass void areas without running cars.

Later, a model using real-time traffic information for in-vehicle route planning was proposed by Nadi and Delavar (2010). In their model, real-time traffic information in each link was detected by certain sensors and depended on the time when the vehicle arrived at that link. Moreover, each link travel time distribution was assumed to be known in advance. At each decision point, the next best link to take was decided by determining the next outgoing real-time link travel time, and the expectation of the minimum of random travel time values towards the destination. Recently, the best route selection framework in a stochastic time-dependent network was ascertained by considering link travel time indeterminacy. Correlations between adjacent link costs with real time information were briefly mentioned by Dong et al (2011), where the correlation between adjacent link pairs were built based on conditional probability theory. This improved Nadi and Delavar's earlier work.

6. Conclusions and future work

The rapid growing market need for in-vehicle navigation systems prompts the development of a more advanced route guidance system, which can be operated in real-time situations and offer benefits for users. This paper provides a survey of the literature to identify relevant advances relating to the in-vehicle route guidance system. The different advances are

categorized into several aspects, such as the basic classification of the route guidance system, major reliability indices and prediction methods, simulation models, and optimal routing algorithms.

Current research outcomes are far from being mature. As to future research directions, it appears most promising to seek a real-time route guidance system that provides accurate, reliable and intelligent suggestions in a timely manner to help motorists navigate to their destination. Under this model, there are several existing challenges, such as communication technology, infrastructure rebuilding, and so on. For the information provision mechanism, a large number of sensors are required to monitor the road situation and a very powerful information centre is needed to process the collected information from the sensors. Therefore, an advanced wireless communication system should be considered, and a hybrid route guidance system can be used to lighten the required computation. A performance evaluation framework with suitable performance metrics (such as reliability, scalability and efficiency) is also required. Systems with real-time information should be further examined in future research.

Also future research is required to look into ways to improve the existing method for a stochastic time-dependent network and also enhance its computation efficiency.

Finally, we believe that the flourishing of a variety of systems, algorithms and techniques, such as improved new global navigation satellite systems, reliable optimal routing choices models, wireless communication technologies and wireless positioning methods, will stimulate further interest and research in the area of in-vehicle route guidance systems, which would bring in more prominent navigation functions and further enhance travel experience.

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