Status and Research Topics in Developing Ecological Transportation System within Connected Vehicle Age with Knowledge Discovery in Database Techniques

Fengxiang Qiao, Qing Li*, Lei Yu

Innovative Transportation Research Institute, Texas Southern University, 3100 Cleburne Street, Houston, Texas, USA

Abstract

Traditional transportation studies normally focus on the development of countermeasures for the improvement of safety and mobility of transportation systems. With the newly identified evidences and increased public concerns, the impacts of transportation activities on environment and ecologic systems attract more and more attentions. This article reviews the current air quality and vehicle emission models and real-time intelligent network control methods in ecological transportation (or called eco-transportation) systems with the efforts in reducing greenhouse gases and exhaust emissions, and improving air quality and public health. The ecological transportation system is considered in a Connected Vehicle environment, and the potential applications of the Knowledge Discovery in Databases (KDD) techniques in ecological transportation system are also reviewed. The proposed research topics can be extended to a better understanding of complex network modeling and controls associated with the development of sustainable urban environment with the ecological transportation system.

Keywords: Ecological transportation system; Eco-driving; Eco-signal; Eco-routing; Connected vehicle; Datamining; Environmental protection

Introduction

Traditional traffic control and transportation management systems mainly focus on the relief of congestions and the enhancement of traffic safety. It is proven however that, the transportation sector is one of the main sources with significant impacts on the environment, the entire climate, the public health, and the entire ecological system [1-4], which is also an increasing general public concern. With the continuous growth and global embrace of the internet-of-things (IOT), wireless communication, and other advanced technologies, the connected vehicle-based eco-transportation system could offer a new definitive mobility that represents a fastest growing sector due to the multidisciplinary research, social, and business opportunities for collaborations among infrastructure, mobile devices, telecommunication and automotive entities. This article therefore focuses on the review of the development of models and algorithms for ecological transportation (or called eco-transportation) systems (including eco-driving, eco-signal and eco-routing systems) and the relevant connected vehicle and Knowledge Discovery in Databases (KDD) techniques. The multidisciplinary knowledge to develop the algorithms, models, and tools for the eco-transportation system could include transportation engineering, environmental science and engineering, mathematics, computer science and engineering, and electronics engineering. Techniques to support these models and algorithms would take account of transportation theories, environmental science, Operations Research (OR), computational algorithms, probability analysis, statistics, KDD (or data mining), machine learning and digital signal processing.

Existing Studies in Ecological Transportation Development

The existing studies are focused on the separate development of ecological transportation (eco-driving, eco-signal, or eco-routing) algorithms. Further, such studies are normally limited to the stage of algorithm development, with few efforts on the implementation and testing of developed applications and models in the field [5].

Eco-driving system

Eco-driving is an approach that incorporates intelligent technologies in driving to minimize fuel consumption, travel costs, greenhouse gas emissions, and other air pollutant emissions, vehicle miles traveled (VMT), vehicle and road degradation, and incident related costs, such as injuries, fatalities and insurance [6]. Eventually, the eco-driving is dedicated to achieve economical, ecological, as well as safe driving [7]. It is reported that eco-driving techniques are able to improve fuel consumption efficiency with up to 30% [8], by providing drivers with a variety of advice and feedback on eco-driving style on board as well as through public education. The advice and feedback include vehicle maintenance, operational decision, such as driving speed, and the use of cruise control, and tactical decisions, such as the route selection and the selection of the road type [9]. More specifically, during an eco-driving practice, an on-board eco-driving system executes a quick analysis and short-term modeling prediction on driving styles and real-time conditions on roads, such as traffic congestion, road grade, and traffic signal. Based on the analysis and prediction results, eco-driving operational decisions are formed and delivered to drivers to adjust their driving behaviors, in terms of driving speed and navigation [10].

Eco-signal system

Eco-signal is a technique that optimizes traffic signal control strategies to minimize fuel consumption and vehicle emissions as well as improve the operational efficiency and safety at intersections [11]. Specific impacts of the eco-signal on drivers' driving behaviors

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are anticipated by microscopic traffic eco-signal models, which can simulate individual vehicle's driving patterns as well as interactions among vehicles in a very detailed manner. An optimal eco-driving pattern is recorded and recommended to drivers. The eco-signal models are often applied to signalized intersections, signal priority for freight and transit, connected eco-driving and wireless inductive/resonance charging. Many studies demonstrated that the performance of the eco-signal system is promising. For example, it was found that traffic signal synchronization could help drivers avoid a stop-and-go activity, thereby reducing waiting time by approximately 21%. Providing advices on eco-driving pattern can contribute to fuel consumption reduction by 20-25%. The eco-signal application can eliminate hard accelerations and deceleration maneuvers, resulting in reductions of 9% energy consumption, 18% carbon monoxide and 25% nitrogen oxides emissions [11].

Eco-routing system

Conventional routing choice models are mostly developed to shorten the travel time, such as Waze application [12], Google map [13] and GPS navigator [13]. In recent years, eco-routing is derived from the routing choice models to minimize total operating costs, including vehicle emissions, fuel consumption and travel time, for the same origin and destination. The eco-routing is a vehicle navigation strategy and was initially proposed. They developed an eco-routing based navigation system to instruct commuters to optimize their route selection, which were applied to 109 real journeys. It was found that 46% of the real journeys were optimized by the navigation system and an average of 8.2% fuel consumption was saved. Other studies demonstrated that slower arterial route and local road are beneficial to fuel consumption reductions. Researchers proposed an eco-routing model to approximate the impacts of major acceleration events associated lane changes and intersection idling. Results show that vehicle specification, especially weight and engine displacement, may affect the fuel consumption from eco-routing.

Connected Vehicle Technologies

Connected Vehicles refer to the wireless connectivity that enables vehicles to communicate with internal and external environments [14], such as Vehicle-to-Vehicle (V2V), Vehicle-to-Road Infrastructure (V2R) and Vehicle-to-Internet (V2I). The wireless connectivity to vehicles was initially proposed to improve the safety and mobility of a transportation system, which annually bring about tremendous economic costs and environmental issues. It is reported that the congestions in 498 U.S. urban areas were equivalent to 121 billion loss in 2011 and 56 billion pounds extra carbon dioxide (CO_2) emissions, which are five times of the congestion costs and CO_2 emissions in 1982, respectively [15].

On the other hand, the demand for every faster mobile data in recent years also facilitates the application of connected vehicles. The U.S. government has been carrying out a Connected Vehicle program to test and evaluate the wireless connectivity technologies to cars, buses, trucks, trains, roads and other infrastructure, and smartphones and other devices [16]. In Western Europe, over one third of all circulating cars would be deployed with the connected vehicle technologies by 2016, which will grow to 90% by 2020 [17].

It is estimated that the connected vehicle program could prevent 592,000 crashes from occurring, and save 1,083 lives [16]. Further, twenty-eight percent of nation's greenhouse gas emissions could be reduced from the transportation sector [18]. Besides, the connected vehicle technologies could boost the development of autonomous vehicles, in which drivers are able to enjoy their travel time by reading e-books, watching movies or other in-vehicle entertainment activities.

Further, due to the deployment of the connected vehicle technology, 25 Gb of data could be generated and uploaded to the cloud hourly, forming a big database [17], which is a significant resource for various transportation related research, such as safety performance, roadway design and environmental and public health impact studies.

KDD Technology and Its Potential Applications in Developing Ecological Transportation System with Connected Vehicles

The huge amount of data generated from different sources in autonomous and connected vehicle systems, could form the fundamental database needed for implementing eco-driving, eco-signal and eco-routing algorithms. The data include but not limited to the current geo-location of vehicles, destination, fuel level, number of passengers in vehicles, traffic control devices, weather, day of the week, road infrastructure, and existing incidents. For each single vehicle, a big portion of the data will be generated every second, thus the data must be managed and kept available to the systems that need it.

For example, it is estimated that each hour a connected vehicle, which may carry embedded mobile broadband chips and on-board computers, will generate a large amount of data that are about a dozen of high-definition movies and exceed the storage capacity of most smartphones today. Since the quantity of data may exceed the bandwidth capability of the current networks, the first big data challenge for connected vehicles to overcome is the sheer quantity of data. One way to address this is to transport less of the data over the network. It will be important to separate the data that can provide real insights from redundant and repetitive information. This requires that at least some of the data analytics be performed onboard the vehicle to find the important pieces of good quality information, and limit the amount of data transported. However, before conducting any data analytics, there must be an understanding of the data lifecycle, knowing which data must be kept and which data can be discarded after a certain period of time.

The relevant big data in urban transportation networks need to be smartly processed utilizing specific big data mining technologies and techniques such as crowdsourcing, cloud computing and federated database systems so that the transportation operators or private sector data service providers can be linked together in extracting values from the connected vehicle and traveler data in complex transportation network [19].

The KDD technology is sometimes called data mining, which is the process to analyze the data from different perspectives and summarize them into useful information for further processing [20]. In a connected vehicle environment, it is important to investigate the potential use of a third-party data broker. The development of data standards is also an important step, especially when the collection and management of the data are from different entities. Data mining approaches are essential so as to reduce the volume of connected vehicle and traveler data while keeping the most valuable information [19]. The big data mining approach can be applied to a wide range of data types and analytical challenges, and there is a great potential for transportation stakeholders to introduce the big data thinking concept into their current activities [21,22].

Emerging Research Topics in Developing Ecological Transportation System

By reviewing the above systems and technologies, the authors feel that there are recently at least four emerging research topics in developing the eco-driving, eco-signal and eco-routing systems under the connected vehicle age.

- The development of comprehensive eco-transportation data and the establishment of eco-transportation and related public health database for urban transportation networks.

- The cutting age eco-driving, eco-signal, and eco-routing models and algorithms that fit into the complex transportation networks while making a full use of the connected vehicle information.

- The advanced KDD algorithms that can be directly used to efficiently manage the big data from connected vehicles in eco-transportation networks.

- The practical and competent tools for eco-transportation system implementation that can be used by drivers of autonomous, connected, and conventional vehicles, respectively.

All these studies need synergic collaborations from a wide spectrum of interdisciplinary subjects and should be implementation oriented. For example, the eco-driving model should consider the expansion of conventional traffic flow dispersion model and all types of connected vehicle messages with an objective to minimize the ecological and environmental impacts. The eco-signal algorithms should include the eco-signal phase and timing for isolated intersection, eco-signal corridors, and eco-signal priority. The trajectory guidance based eco-routing models provide dynamic information to drivers with the real-time information exchanges from vehicle to vehicle, vehicle to Road Side Unit (RSU), and vehicle to cloud. A heuristic nonlinear programming formulation of the dynamic user-equilibrium (DUE) traffic assignment algorithm should be able to function well in the complex urban transportation networks with multiple trip origins and destinations. The practical tools should be designed and tested to implement the eco-driving, eco-signal and eco-route algorithms and models. The guidance messages to drivers with vehicles of different types of automations and communication settings should be tested and adjusted in the simulated environment first, while the developed tools and models should be further tested in the field with various practical scenarios using necessary hardware and software specially developed.

Conclusion

This article focuses on the review of national and international vanguard research needs in air quality and emission modeling and simulation, and in ecologically oriented transportation management theories. It is believed that with multidisciplinary research approaches including connected vehicle and KDD, the expectant countermeasures needed for urban environment network systems will be resulted in through the proper development of eco-driving, eco-signal and eco-routing models and algorithms for reduced pollutions to the environment and improved air quality.

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