Intelligent transportation systems based on computer aided simulation method

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Abstract

Road transportation is one of the main sources of greenhouse gas emissions, which lead to global warming and climate change. Promoting the decarbonisation of this sector through more efficient and greener mobility is a challenging task that can be achieved by intelligent transportation systems (ITS) enabled by vehicular communications. Intelligent Transportation Systems (ITS) have been developed for more than ten years in China. Furthermore, a new generation Intelligent Transportation Systems should be launched to meet the requirement of rapid development of transportation in China. For the last two decades, intelligent transportation systems (ITS) have emerged as an efficient way of improving the performance of transportation systems, enhancing travel security, and providing more choices to travellers. A significant change in ITS in recent years is that much more data are collected from a variety of sources and can be processed into various forms for different stakeholders. This paper presents an overview of the background, concepts, basic methods, major issues, and current applications of Parallel transportation Management Systems (PtMS). In essence, parallel control and management is a data-driven approach for modelling, analysis, and decision-making that considers both the engineering and social complexity in its processes. The developments and applications described here clearly indicate that PtMS is effective for use in networked complex traffic systems and is closely related to emerging technologies in cloud computing, social computing, and cyber physical social systems.

Keywords: agents, intelligent transportation systems (ITS), mobile agent systems, multiagent systems

1 Introduction

In the European Union (EU), the majority of the population (72%) and economic development [85% of the gross domestic product (GDP)] concentrates in urban areas according to [1]. However, mobility in these areas is strongly constrained, i.e., by traffic and inefficient (private and/or public) transportation. These inefficiencies lead to congestion, pollution, noise, increased energy consumption, and the associated economic losses. For instance, in the USA, congestion wastes a massive amount of time, fuel, and money. i.e., 1.9 billion gallons of wasted fuel, 4.8 billion hours of extra time, and 101 billion dollars of delay and fuel cost [2]. In the EU, congestion costs 1% of the total GDP annually [3].

Recently, there has been significant interest and progress in the field of intelligent transportation systems (ITSs) from both industry and academia. The main contribution of ITSs is to significantly increase road safety. However, the role of infotainment has rapidly taken an important place [4]. The new emerging infotainment applications or safety-related mobile applications call for vehicular communication networks to support seamless wireless Internet services in fast-moving vehicles [5]. Internet access in automotive scenarios is a particularly relevant case, particularly because people in modern cities spend much time in transportation and vehicles. Public transportation systems, such as subways, suburb trains, and city buses, represent one relevant scenario because of a group of users and the time spent by these users in transportation and vehicles [6].

There are many challenges in conducting full-scale ITS research, particularly when vehicles are involved. For example, modifying conventional vehicles to autonomous vehicles is usually costly in terms of money and time. Testing in real traffic environments is usually dangerous. Such challenges have posed significant obstacles to many researchers in ITSs and forced them to use pure computer simulation [7], in which it is extremely hard to mimic certain aspects such as communication, vehicle dynamics, and driving experience. For many ITS research problems, a scale-down platform may be very useful for preliminary study and feasibility tests. However, there is very limited previous work in developing such a multipurpose ITS research platform. First, congestion has become an increasingly important issue worldwide as the number of vehicles on the road increases. For example, Beijing, China, had a total of 4 million vehicles at the beginning of 2010 and added another 800,000 in that year. Congestion can lead to an increase in fuel consumption, air pollution, and difficulties in implementing plans for public transportation [8]. It can also increase the risk of heart attack, as indicated by a medical report [9]. Second, accident risks increase with the expansion of transportation systems, particularly in several developing countries. Zheng et al. [10] showed that in China, there were 104,373 fatalities in 2003 and 67 759 fatalities in 2009. It was pointed out by Malta et al. [11] that almost three fourths of all traffic accidents can be attributed to human error. The reports published by the

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U.S. Federal Highway Administration indicated that traffic accidents that happened in cities account for about 50%–60% of all congestion delays [12]. Undoubtedly, there is a need to reduce traffic accidents and to detect accidents once they have occurred to minimize their impact. Third, land resources are often limited in several countries. It is thus difficult to build new infrastructure such as highways and freeways. After the terrorist attacks in New York City on September 11,2001, the effectiveness of transportation systems is increasingly tied to a country's capability to handle emergency situations (e.g., mass evacuation and security enhancement) [13]. The competitiveness of a country, its economic strength, and productivity heavily depend on the performance of its transportation systems [14].

The domain of traffic and transportation systems is well suited to an agent-based approach because of its geographically distributed nature and its alternating busy-idle operating characteristics [15]. From the traffic and transportation management perspective, the most appealing characteristics of agents are autonomy, collaboration, and reactivity. Agents can operate without the direct intervention of humans or others. This feature helps to implement automated traffic control and management systems. Agents are collaborative. In a multiagent system (MAS), agents communicate with other agents in a system to achieve a global goal. Agents can also perceive their environment and respond in a timely fashion to environmental changes. Agent-based transportation systems allow distributed subsystems collaborating with each other to perform traffic control and management based on real-time traffic conditions. A distributed vehicle monitoring test bed presented in [16] is an early example of the distributed problem-solving network. Recently, more and more agent-based traffic and transportation applications have been reported. Our literature survey shows that the techniques and methods resulting from the field of agent system and MAS have been applied to many aspects of traffic and transportation systems, including modelling and simulation, intelligent traffic control and management, dynamic routing and congestion management, driver-infrastructure collaboration, and decision support. This paper reviews agent applications in traffic and transportation systems. These applications are classified into five categories: 1) agent-based traffic control and management sys-tem architecture and platforms; 2) agent-based systems for roadway transportation; 3) agent-based systems for air-traffic control and management; 4) agent-based systems for railway transportation; and 5) multiagent traffic modelling and simulation. The selected projects in each category are listed in a tabular format with information of project name, research group, application domain, and key features.

2 Related work

ITS aim to streamline the operation of vehicles, manage vehicle traffic, and assist drivers with safety and other information, along with provisioning of convenience applications for passengers [17]. In [18], these applications have been classified into three main categories: 1) safety-related applications (e.g., collision warning); 2) traffic efficiency and management (e.g., speed management); and 3) infotainment and entertainment (e.g., cooperative local services). In this paper, we will rather focus on traffic efficiency and management applications since these have a direct impact on traffic flow, vehicle coordination, and information dissemination. This last application type can be further subdivided into (as partly done in [19]): 1) speed management (provide regulatory or recommended contextual speed information to drivers to improve road efficiency); 2) navigation (information and services provided to drivers to assist in-vehicle routing); 3) road systems (e.g., traffic management systems); 4) vehicle control [e.g., adaptive cruise control (ACC)]; and 5) driver-related services (e.g., eco-driving).

Over the past decade, ITS technologies have greatly improved traditional transportation conditions, and improved the traffic capacity of the road network and transport security in China. In 1999, the National Engineering Technology Research Center of Intelligent Transportation System (ITS) was established. Many universities and research institutions also set up ITS Research Center to research ITS theories and technologies. The Tenth Five-Year period (2001-2005) first took the fields of intelligent transportation systems as content of the national planning. In 2001, China had selected ten cities as model cities for ITS field testing and evaluation. Those cities included Beijing, Shanghai, Guangzhou and so on [20]. During this period, many important aspects and key issues in ITS research and development were addressed on a high scientific and engineering level: agent-based and vision-based technologies; traffic modelling, control, and simulation; communication and location-based services; and driving safety and assistance, etc. For instance, the digital bus station systems has come into use in many cities, such as Beijing, Guangzhou, Chongqing, Shanghai, Hangzhou, Shenzhen, Nanjing, Shenyang, etc. Many information technologies of this system, such as computer control technology, wireless network communication technology and LED display control had been completely developed. During the Eleventh Five-Year period (2006-2010), ITS had more opportunity to develop, especially in transport services for major international events. Olympic traffic management command and control system was established in Beijing in 2008. Which include bus operations management system, floating vehicle dynamic traffic information collection processing and publishing systems. These systems have four major functions: command, signal control, integrated monitoring and regional traffic optimization. The systems comprehensively support Beijing public security traffic management work in 2008 Olympic.

3 Simulation based ITS

The operation of agents is supported and managed by distributed software platforms known as agent systems. The name of MASs usually refers to systems that support stationary agents, and mobile agent systems support mobile agents. An agent system provides mechanisms for agent management, agent communication, and agent directory maintenance. A mobile agent system provides additional mechanisms to support the migration and execution of mobile agents. In an agent system, agencies are the major building blocks and are installed in each node of a networked system, in which agents reside and execute. To facilitate the interoperation of agents and agent systems across heterogeneous agent platforms, agencies designed to comply with agent standards are highly desired.

The integration of a driving simulation and traffic simulation environment may be achieved by implementing a communication structure that can effectively exchange data between the two applications (see Figure 1).

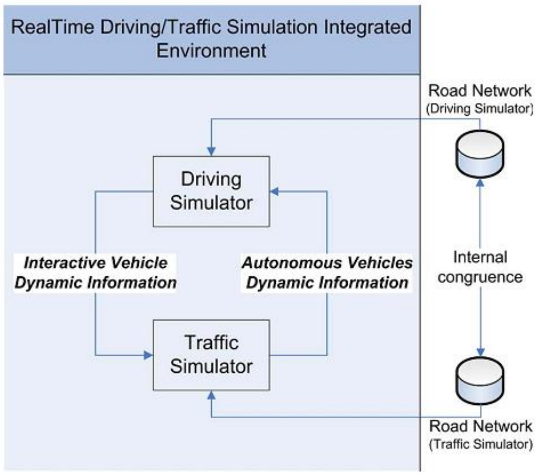

FIGURE 1 Communication framework

The integrated environment has to ensure that, during the driving simulation, the autonomous vehicles are consistently moved by the traffic microsimulation model with the movements of the interactive vehicle. Furthermore, during the simulation, the software that manages the driving simulator needs to send the kinematic characteristics of the interactive vehicle (e.g., position, angle, and speed) to the traffic-simulation model. Once such information has been received, the traffic-simulation model can calculate kinematics of the surrounding traffic for the step ahead and send them back to the driving simulation environment, which has the task of updating this information in the driving scenario.

To implement the communication framework, it is necessary to tackle several issues, which are summarized as follows. Accurate Road Matching Between Traffic and Driving Modules: The first issue for integration is the consistency between the road networks: Position related data to be exchanged have to be framed within a well-known reference system to allow appropriate conversion between the two environments during communication. The two road networks thus have to exactly match to have strict correspondence between the two simulation environments.

With regard to the first aspect, there is a simple way of overcoming the problem. Network creation usually starts in both software applications with importing the road alignment. Both types of applications should import drawing files (.dwg) or shape files (.shp). Thus, it is only important to avoid any transformation of geographical information during the import process to ensure the consistency of the two reference systems. This way, data retrieved by the two environments are ready to be exchanged. As for the road matching problem, this case is mainly because a driving simulator requires very detailed road geometry to present the road as realistically as possible for the driver, which is obviously far from the purposes of a microscopic traffic simulator, where, in most cases, for instance, the road alignment curvature, even when represented in detail, does not affect vehicle behavior.

Synchronization of Traffic and Driving Modules with Real Time: As aforementioned, the communication framework has to allow real-time data exchange required to perform a driving simulation. Unlike the driving simulation engine, traffic microsimulators are not designed to work in real time, but according to the hardware performance and scenario complexity, they try to perform all the needed calculations in the shortest time. This condition means that the time needed for a simulation is usually shorter than the real time and generally involves the need to slow down the computing speed of the traffic-simulation package. However, if the amount of data to be exchanged is large, the traffic module may slow down to less than real time. This case would naturally rule out any chance of successfully integrating the modules.

Consistency of the Updating Calculation Frequency: Each simulation model performs calculations at a given frequency. The finer the desired outputs are, the higher the updating frequency of calculations becomes. Both the microscopic traffic-simulation model and driving simulation software work this way. The difference is that the minimum simulation step in traffic simulation is usually 0.1 s, whereas realistic visualization in a driving simulation environment needs information to be updated at a higher frequency (generally 60 Hz). Therefore, if higher simulation frequency is not allowed by the microsimulation software (or it would slow down the simulation speed to below the real-time speed), outputs have to be augmented, e.g., through interpolation. Management of Autonomous Vehicle Visualization: This issue is twofold. First, a microscopic traffic simulation can manage thousands of vehicles at the same time. The management of such a large number of vehicles in a driving simulation environment is unfeasible for the aforementioned real-time issue and useless for driving simulation purposes. Hence, only the information of vehicles that surround the interactive one is exchanged during the simulation, which can be done by defining a "bubble" around the interactive vehicle. It is thus necessary to create, on the one hand, a vehicle in the traffic model to reproduce the movements of the interactive vehicle (maneuverer by the driving simulator) in the traffic simulation environment.

On the other hand, in the driving-simulation environment, a certain number of "ghost" vehicles have to be created, which come into action when some vehicles enter the bubble in the traffic simulation. When a vehicle enters the driving simulation, a clear one-to-one correspondence has to be created with the corresponding one in the traffic simulation. More specifically, as long as a vehicle in the traffic simulation stays within the surroundings of the interactive vehicle, it always has to be represented by the same vehicle in the driving simulation. Both aspects of this issue have to specifically be dealt with and, depending on how the solutions are implemented, can seriously affect the possibility of having a real-time data exchange. The aforementioned issues do not constitute the exhaustive list of problems to deal with when implementing integration. They are, however, the most basic issues to obtain an effective framework. Additional issues may arise, depending on the particular driving and traffic simulation models used, as well as on the particular strategy adopted. The framework implemented in a particular case study, and the way in which such issues have been taken into account are shown as follows.

4 System Architectures and Operation Process

4.1 SYSTEM ARCHITECTURE AND OPERATION PROCESSES

Figure 2 presents the system architecture of ACP-based PtMS. It should be pointed out that normally, there is more than one ATS used in parallel traffic control and management. For example, different ATS can be created, respectively, for the purposes of historical traffic situations, normal and average performance, optimal and ideal operations, or worst-case scenarios for disasters and emergency management. Through interaction and parallel operations between an actual transportation system and its corresponding multiple ATS, the effectiveness of different traffic strategies under various conditions and expectations can be evaluated and analysed, both offline and online, and useful information can be obtained timely and combined to generate and select decisions for control and management.

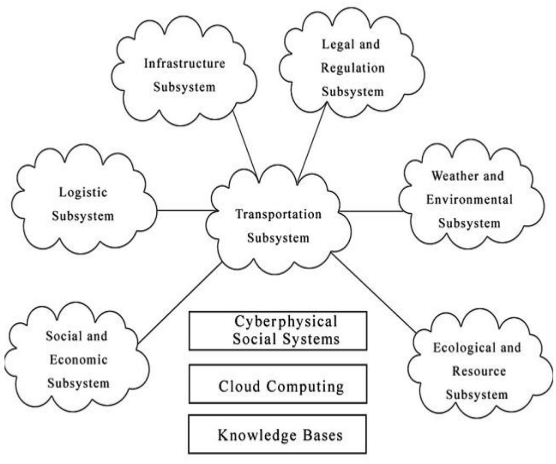

FIGURE 2 Scope, framework, and facilities of ATS

Typically, PtMS consist of five major components: 1) actual transportation systems; 2) ATS; 3) traffic operator and administrator training systems (OTSt); 4) decision evaluation and validation systems (DynaCAS); and 5) traffic sensing, control and management systems (aDAPTS). The operation process of PtMS is based on the co-evolution of real systems and the corresponding ATS. The operation process can be divided into three modes: 1) training; 2) testing; and 3) operating. General operational procedures can be derived from the functional specification of operating systems OTSt, Dyna CAS.

4.2 TRAINING AND LEARNING

Operator Training Systems for transportation (OTS) is developed for learning and training mode operations for traffic operators and administrators. The use of OTS was partially inspired by the applications and success of operator training simulation in many other advanced and complex industrial operations, such as in petrochemical production processes. Task requirements and procedures for both regular traffic operations and emergency situations are incorporated into OTS in order to make its functionality more useful and closer to reality. Sessions by OTS can be generated manually by human operators or automatically by agent programs. Manual sessions are also used to collect behavioral data from trainees and learners. Using agent-based behavioral modelling, automatic sessions can be employed when conducting accelerated testing and evaluation on the reliability and effectiveness of traffic operational procedures and regulations.

4.3 TESTING AND EVALUATION

Dynamic network assignment based on Complex Adaptive Systems (DynaCAS) is constructed to design, conduct, evaluate, and verify computational transportation experiments, detect existing and emerging traffic patterns, and support the use of advanced traveler information systems, advanced traffic management systems, and other ITS modules. DynaCAS facilitates the estimation and predication of traffic network conditions, performance testing and evaluation of different traffic control and management measures and information dissemination strategies, and decision support to traffic operators and individual drivers. Using ATS, DynaCAS is able to pay special attention to rule-based computational modelling of the social and behavioral aspects of people, vehicles, roads, and environments involved in transportation activities. In addition to conventional microscopic, mesoscopic, and macroscopic specification, a level of logic representation has been introduced in DynaCAS to represent the transportation networks so that factors in social and economic, ecological and resource, construction and infrastructure, logistical, legal, and regulatory aspects can easily be incorporated. On the logic level, transportation modelling extensively employs qualitative information in linguistic forms, and computing with words and methods in linguistic dynamic systems is used to achieve quantitative analysis. Data-mining techniques are also used to discover useful patterns from simulation results and computational experiments on all levels. Compared with other traffic estimation and predication systems (TrEPS), such as the well-known DynaSMART and DynaMIT, methods in AI and complex systems are much more extensively used in DynaCAS to provide additional flexibility and efficiency in traffic-condition analysis and decision evaluation.

4.4 CONTROL AND MANAGEMENT

Agent-based Distributed and Adaptive Platforms for Transportation Systems (aDAPTS) is built to provide supporting and operating environments to design, construct, manage, and maintain autonomous agent programs for various traffic tasks and functions. Those agents are delivered to traffic-control centers, roadside controllers, sensing devices, and information systems via communication networks to make the right decisions and collect the right information at the right time. We have designed and manufactured special intersection light controllers and sensing systems that are capable of hosting and processing traffic-control agents for different functions. Generally, an agent can autonomously move in networked environments, identify its tasks, and actively improve its performance. Transitioning from traffic-control and management algorithms to traffic-control and management agents is a natural step forward in this age of networks and connectivity. This step enables an intelligent and proactive mechanism that will significantly improve the performance and reliability of traffic operation control and management, yet it will have low cost for networked transportation systems.

Traffic task agents can be distributed at different operating centers and information sites. To ensure a coherent control and communication mechanism among those agents, we must integrate and coordinate their objectives and activities. A hierarchical intelligent control architecture consisting of organization, coordination, and execution levels has been used to facilitate the activities and operations of traffic agents, which is shown in Figure 3.

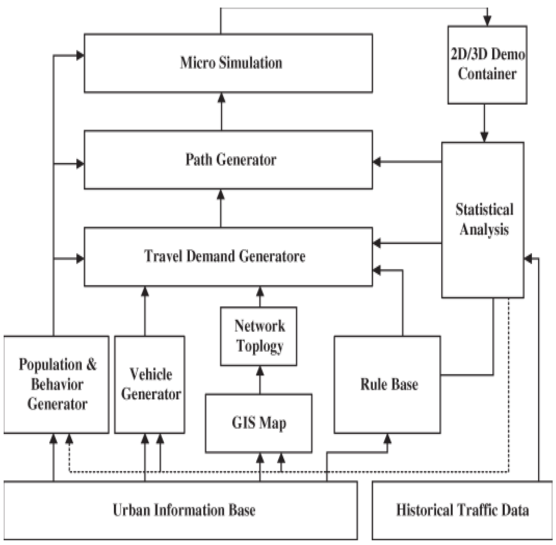

FIGURE 3 System architecture and components

InaDAPTS, a global traffic operating center (GTOC) (virtual or real) is designed to construct, organize, and maintain different types of agents for various traffic tasks, such as intersection light control, traffic-incident detection, and route guidance. WANs link the GTOC to several regional traffic-operating centers (RTOC), which host various agent repositories for regional demands and requirements of traffic control and management. RTOC coordinate and dispatch traffic agents to thousands of intersection light controllers, ad hoc networks, display devices, and guidance equipment at hundreds of locations. At each location, a gateway downloads task agents from WANs to traffic controllers, sensors, displayers, etc. through LANs and uploads information and requests from traffic devices to RTOC. Each location also has an agent coordinator to conduct cooperative control and management among traffic devices and within an individual device. Clearly, there is a natural link between PtMS and CPS, CPSS, and cloud computing. For example, CPS can be used to implement smart intersection traffic-control systems via aDAPTS, CPSS can be employed to build ATS in cyberspace and construct intelligent web-based DynaCAS and OTS t, and cloud computing is a cost effective way to host and operate the entire PtMS.

5 Conclusions

Road transportation is one of the main sources of greenhouse gas emissions, which lead to global warming and climate change. Promoting the decarbonization of this sector through more efficient and greener mobility is a challenging task that can be achieved by intelligent transportation systems (ITS) enabled by vehicular communications. Intelligent Transportation Systems (ITS) have been developed for more than ten years in China. Furthermore, a new generation Intelligent Transportation Systems should be launched to meet the requirement of rapid development of transportation in China. For the last two decades, intelligent transportation systems (ITS) have emerged as an efficient way of improving the performance of transportation systems, enhancing travel security, and providing more choices to travellers. A significant change in ITS in recent years is that much more data are collected from a variety of sources and can be processed into various forms for different stakeholders. This paper presents an overview of the background, concepts, basic methods, major issues, and current applications of Parallel transportation Management Systems (PtMS). In essence, parallel control and management is a data-driven approach for modelling, analysis, and decision-making that considers both the engineering and social complexity in its processes. The developments and applications described here clearly indicate that PtMS is effective for use in networked complex traffic systems and is closely related to emerging technologies in cloud computing, social computing, and cyber physical social systems.

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