

An Overview of Artificial Transportation Systems

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Abstract — At present, the problems of urban traffic management and control have not yet been well solved, due to the great complexity of urban transportation systems. In this context, artificial transportation systems (ATS) theory was presented several years ago, and has been verified to be a promising approach to better management and control of complex transportation systems. On the basis of summarizing the research works on ATS to date, this paper systematically introduces the concept, theory frame and methods of ATS; meanwhile, the corresponding literatures are also reviewed. Then, as a major application approach of ATS, the parallel system theory is briefly introduced, and the major case studies of applying ATS are also reviewed. Finally, we analyze the current state-of-the-art of ATS, and point out the main research directions.

Keywords—artificial transportation systems; transportation simulation systems; agent method; parallel transportation management systems

I. INTRODUCTION

Traffic problems, as a sort of the key problems of urban development and management, have resulted in a huge impact on the social development. In many big cities, the traffic problems have formed a bottleneck of economic and social development and have become one of the culprits to environment pollution. However, as a research object, transportation systems not only have characteristics, such as multidisciplinary, interdisciplinary, large-scale, high complexity, but also have the high cost, which makes it very difficult to do experiments directly on the real transportation systems. Therefore, it is quite difficult to comprehensively test and accurately evaluate the solutions for traffic problems in advance, which is also one of the reasons why the existing intelligent transportation technologies are not able to solve the traffic problems completely yet [1].

After several decades of development, transportation simulation systems (TSS) have become an important tool in the research of transportation systems, and have been widely and effectively applied in practice. Typical TSS include CORSIM, VISSIM, TransModeler, Quadstone Paramics, etc. However, along with the increase of computer capacity and speed, and also the popularization of parallel, distributed and grid computing methods, the limitations of the traditional transportation simulation approaches become obvious, and these approaches are not able to take full advantages of the high performance of current computers [1], [2].

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Under this background, Wang *et al.* [1-3] proposed the concept of artificial transportation systems (ATS), by which the transportation simulation methods were improved to a higher level. In this paper, we systematically discuss the ATS theory and method. First, the question what is ATS is comprehensively answered in three aspects: 1) the definition of ATS; 2) the differences between ATS and TSS; 3) the basic framework of ATS. Then, the research methods of ATS are discussed in detail, and the case studies are also reviewed after the method description. Finally, as a major application approach of ATS, the theory of parallel systems and its applications are briefly discussed.

II. ARTIFICIAL TRANSPORTATION SYSTEMS

A. Definition of ATS

The main idea of ATS is to integrate the artificial society theory and method [4] into transportation simulation methods, and to apply the technologies of high-performance computing and agent-based modeling to transportation systems, i.e. “artificial transportation systems” [1-3]. It is a direct application of artificial societies in transportation simulation systems, and is also the novel requirement of the traditional simulation methods in the research of complex systems and the inevitable outcome of the increasing computing performance.

B. Differences between ATS and TSS

As an important application of computer simulation technology in the field of traffic engineering, transportation simulation uses modern computer technology to reproduce the complex traffic phenomena. By using TSS to analyze the possible behaviors of transportation systems under various conditions, the users try to find the optimal solution for the traffic problems in the real world. Compared with TSS, ATS has both similarities and differences.

The similarities: On one hand, the research thoughts of ATS and TSS come down in one line. ATS just change an angle and try to use the new method to solve the same problem, which is how to analyze the complexity of transportation systems. On the other hand, they are both based on the traffic theory research, and use the computer technologies to study the complex traffic phenomena by developing the virtual mathematical models or computer-implemented models.

The differences: The most important difference lies in that the fundamental starting point of building ATS and TSS is different. TSS first divide the research object into subsystems,

then use computer and numerical technologies to perform modeling and integrating, and finally simulate and replay the status and development characteristics of the real transportation system, so as to discuss and solve the various problems faced by the real traffic. It belongs to a top-down passive reduced-style research method. However, ATS employ computer and agent technologies to build transportation systems. Starting with the traffic behavior models of a single vehicle or a local object, ATS explore the emerged characteristics caused by the interaction between agent and agent, agent and environment, and environment and environment; meanwhile it shows the various states and development characteristics of ATS. It belongs to a bottom-up initiative synthesized-style research method. Second, both of the systems are also slightly different in terms of the system functions. ATS have self-organization. With the passage of time, it is able to rely on its internal strength to realize its internal ordered, so that its functions can be achieved. Different from ATS, TSS achieve its own balance not relying on its internal strength but completely under the external control.

However, regardless of the differences between ATS and TSS in the objectives, methods, and understandings, their essence is the same, which is to use computational methods to study the traffic problems.

C. Basic Framework of ATS

As the aforementioned characteristics, ATS are self-contained with respect to the generation and evolution of the traffic behavior. Therefore, constructing an ATS not only involves the transportation itself, but also involves the interaction between traffic and people, traffic and nature, transportation and society.

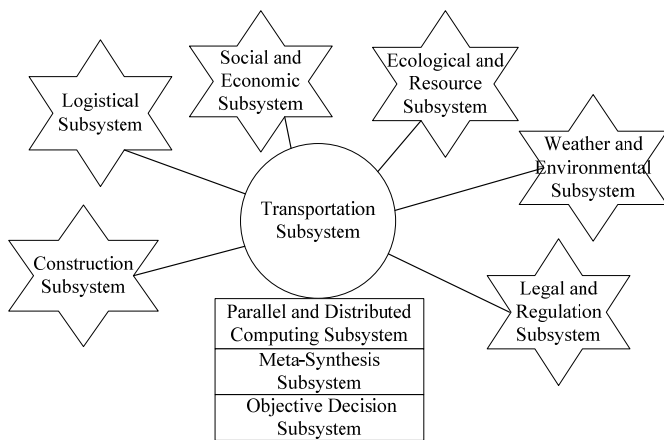


Fig. 1. Major components of ATS.

Figure 1 shows the major components of ATS, including

1) *Transportation subsystem:*

It involves transport infrastructures, vehicles, travelers, management and rules, etc.

2) *Construction subsystem:*

It involves infrastructure construction, the introduction of new technology, etc.

3) *Logistical subsystem:*

It involves freight warehousing, network, scheduling, etc.

4) *Social and economic subsystem:*

It involves population, economic, commercial activities, large social group activities, etc.

5) *Ecological and resource subsystem:*

It involves environmental pollution, ecological cycle, resource consumption and re-use, etc.

6) *Weather and environment subsystem:*

It involves weather, climate, environment conditions, etc.

7) *Legal and regulation subsystem:*

It involves administrative regulations, traffic laws, etc.

8) *Parallel and distributed computing subsystem:*

It involves parallel, distributed, and grid computing, experimental design, etc.

9) *Meta-synthesis subsystem:*

It involves data mining, multiple-factor synthesis, decision evaluation, etc.

10) *Objective decision subsystem:*

It involves object strategy, task planning and assignment, etc.

Among them, logistical, construction and regulation subsystems are closely related with the operation of the entire transportation system; weather and environment, social and economic, and ecological and resource subsystems have a significant impact on the state of the transportation system; parallel and distributed computing, meta-synthesis and objective decision subsystems directly service for the transportation system, and are responsible for the calculation process, comprehensive analysis and indicator assessment in ATS. It should be noted that these subsystems are not only directly related to the transportation system but also interrelated among themselves. Herein, we only consider those relations that affect traffic behaviors.

III. RESEARCH METHODS OF ATS

Obviously, the existing methods for TSS and its subsystems can all be used in the modeling and construction of ATS. Besides, according to the methods used by artificial societies and the latest progress of the complex system and computational intelligence fields, the constructing methods of ATS also involve the following four aspects [5], [6]: 1) agent methods; 2) Petri nets and its derivative models; 3) linguistic dynamic description of complex systems; 4) cellular automata and its generalized form. In this section, these new research methods are successively discussed, with which some typical research literatures are also reviewed.

A. Agent Methods

Agent methods are the primary means of describing artificial societies and many other complex systems. The main features of agents include autonomy, social skills, learning and evolutionary adaptive abilities, and moving ability. Employing

agents to realize the description and analysis of ATS includes three components: the agents, the environment of agents, and the social rules, which are discussed as follows.

1) Agents:

Agents can be various personnel, vehicles, equipments, regulations, even plants, etc. in ATS. They have their own internal states, rules of behavior, ways of thinking, and growth process, which can change with time, communication and external environment. For instance, in the modeling of ATS, each moving vehicle is treated as a traffic agent. Every traffic agent has its internal state and rule, can communicate with the outside world, and can vary with the change of time and space. Generally, traffic agents refer to those subjects who bear abilities for intelligent thinking and can participate in the traffic operation.

2) Environment:

Environment is the place that agents run in. It may be the actual physical environment or a virtual mathematical or computational process. Specifically, the environment of ATS refers to traffic junctions, roads, lights, detectors, gas stations, shops, communities, etc., which form the activity space for agents. In ATS, the changes of the environment may be caused by the emerged traffic phenomena under different conditions. Meanwhile, the new nurtured traffic junctions and road sections can also be used to study their impact on the operation of ATS.

3) Rules:

Rules are the standards and methods of the interactions between agent and agent, agent and environment, and environment and environment. For instance, a simple interaction rule between an vehicle agent and the environment can be the vehicle agent turns left, turns right, goes straight or stops according to the traffic signals at the road intersections; for the case of interactions between agent and agent, a rule can be that a single vehicle agent accelerates, decelerates, or changes lanes, according to other vehicle agents' traveling speed or the road conditions on the same road; according to the emerged traffic characteristics, a simple interaction rule between environment and environment is to design the new traffic junctions and sections.

As one of the important research approaches of ATS, the agent methods have been widely studied in recent years. Miao *et al.* [7], [8] preliminarily investigated the application of the P2P computation techniques and the concept of the social computing in ATS. They established the agent models of vehicles, transport facilities, and shopping malls, and focuses on elaborating the method and procedure of using the P2P communication mechanism to construct the ATS. The feasibility of the proposed method was validated by the simulation example of the single commercial subsystem (population, weather and environment subsystems were not included). Finally they also discussed the issues on the operating strategy and mechanism of ATS. Li *et al.* [9] designed the ATS based on iteration of the rules, and proposed

the ATS model with multi-agent platform group and its computational experiment methods. Miao *et al.* [10] realized ATS modeling and computational experiments on the game engine platform, in which the population module, the traffic simulation module, rules, networks and the interaction were flexibly designed under one framework, and eventually realized the distributed traffic simulation.

B. Petri Nets and Its Derivative Models

Petri nets were originally proposed by Petri in the 1960s in order to describe the communication between the finite automata. Currently, it has been extensively and effectively used in the communications, networking, computation, computer-integrated manufacturing, intelligent systems, project management, and workflow analysis. Recently, many researchers are committed to applying Petri nets into the transportation systems and the agent methods. The use of Petri nets, we can establish the analytic representation of the agent behaviors and the agent social process, and lay the foundation for agent-based ATS design, implementation and verification. The main research directions in this area include:

- 1) *The use of Petri net transducers to establish a single agent in the form of model;*
- 2) *Establishing the Petri net model of the agents' social skills to analytically describe the communication and connection between the agents;*
- 3) *Using Petri nets to describe the agents' mobile ability;*
- 4) *Using probability Petri nets to establish the model describing the agent's reasoning, learning, evolutionary and adaptive ability;*
- 5) *Introducing the game theory to describe the producing and influence of the cooperation, antagonism, decision-making between agents.*

Zhu *et al.* [11] established the ATS model with the two key factors: the agent and the interaction between agents. They put the whole system model as a sequential communication system (a special type of Petri nets), and also demonstrated that the established Petri nets model has good performance by studying the road network modeling case.

C. Linguistic Dynamic Description of Complex Systems

The essence of language dynamic research is how to dynamically and effectively use information to solve the problems on modeling, analysis, control and evaluation of complex systems in the language level. Its main idea is to study how to make use of the effective concept, framework, and methods of the general numerical dynamic to build its own corresponding system. Currently, the main research contents include the concept system, computational frame, and the algorithms of word-digital conversion and digital-word conversion, whereas the main methods involve fuzzy logic, cell space and cell mapping, number theory grid point sets, and discrete dynamic programming. The ultimate goal of language dynamics research is to establish the bridge between human language knowledge representation and computer digital knowledge representation, and becomes one of the basic theories of the next generation intelligent and language-form

human-computer interaction. Language dynamics are mainly applied in the abstraction analysis of numerical dynamic systems, the dynamic analysis of the word-described economic, social, management, and ecological systems, decision-making synthesis, policy evaluation, and the knowledge mining, dynamic representation, and their application of large amounts of data. As the establishment and analysis of ATS involve many intuitions of language representation, experience knowledge and the corresponding reasoning and planning, and data and knowledge mining, language dynamics play an important role in the ATS research.

Wang and Lansing [12] introduced the ontology knowledge base into the ATS, and first represented the concept of ATS with the ontology. Thus, ATS can make full use of web open-source information and the third-party information systems in the semantic level to promote knowledge sharing and reuse. On this basis, they further adopted logic language to formally describe the rules in the simulation process, in order to enhance simulation flexibility and understandability, and also used the knowledge base to implement the centralized management of the ontology and rules.

D. Cellular Automata and Its General Form

Cellular automata and Neumann first proposed self-reproduction automata have been proved by the research on artificial societies that they are the effective tools to realize the analytical model of agents and the calculation process. In recent decades, cellular automata have also been widely used in the studies on traffic behavior. The typical works include the one dimension cellular automata model proposed by Nagel *et al.* for freeway traffic, and the two-dimensional cellular automata model, which is put forward by Biham for urban traffic. Recently, some researchers further presented the generalized cellular automata model, which can also be applied in ATS.

IV. PARALLEL SYSTEM THEORY AND APPLICATIONS OF ATS

Transportation systems are a sort of huge complex systems with dynamics and unpredictability. In order to apply ATS into actual traffic engineering to optimize transportation systems, the parallel system theory (PST), as an effective solution, was developed in transportation management and control [13], which are the parallel transportation management systems (PtMS) [14]. In this section, we first introduce the basic concept of PtMS, and then review the up-to-date researches on the application of ATS.

A. Basic Concept of PtMS

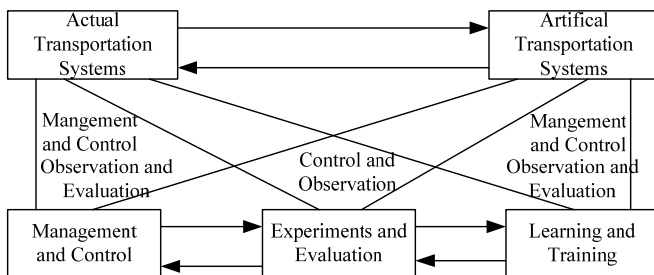


Fig. 2. Basic framework of PtMS.

PtMS changes the traditional passive and offline methods using traffic simulation, and realizes rolling online improvement and optimization for the running transportation systems. The basic framework of PtMS is shown in Figure 2.

The mechanism of PtMS is to use the interactions between the actual transportation systems and ATS to achieve observation and investigation of the physical system, the optimization and management of the actual transportation systems, the experiments and evaluations of the corresponding solutions and decisions, etc. Through the repeated coordination between the two systems, PtMS not only can perform the rolling improvement and optimization of the running traffic management and control system, but also can improve the managers and users' learning efficiency and operating reliability. The main contents include

1) Experiment and evaluation [15]:

By acquiring real-time traffic data, PtMS employ the ATS simulation software to comprehensively and accurately perform the experiment, analysis and evaluation of the transportation system solutions according to the different index systems. This is a big promotion of traffic simulation on the experimental methods, which is also more scientific and reasonable.

2) Learning and training:

As a learning, training and management center, ATS can be connected or combined with the actual transportation systems to implement the "virtual" training to the managers and users of the transportation systems, in order to improve the learning efficiency and operating reliability.

3) Optimization and control [16]:

By connecting ATS with the actual transportation systems to compare them in real time, PtMS perform the rolling improvement and optimization of the actual transportation management and control system. Furthermore, PtMS can predict the future traffic states and correspondingly adjust the management and control modes to achieve better effect of optimization, improvement or control. Meanwhile, the ATS can also be revised to reduce the differences with the actual transportation systems.

B. Applications of ATS

In the framework of PtMS, ATS have been widely studied and practiced during recent years. For instance, Lv *et al.* [17] investigated the problem how to use ATS to evaluate the operation status of transportation systems, under the given conditions of urban land utilization and traffic networks. In their studies, some indices, such as the ratio of congested roads in peak hours and the maximum number of vehicles in road networks, were employed to reflect the traffic operation status of the road networks, which can provide decision support for traffic management departments to formulate transportation development plans. Zhu *et al.* [18] successfully realized the ATS in Ji'nan city of China, and showed positive effectiveness of applying the ATS methods. In the meantime, Xiong *et al.* [19] built the PtMS in Guangzhou, China to enhance smoothness, safety, efficiency, and reliability of public transport management during 2010 Asian (Para) Games. Li *et*

al. [20] studied the computational experiment method in the parallel public transportation system, and obtained better results. Li *et al.* [21] applied the ATS theory in the urban transit system, which was called artificial urban transit system (AUTS). With AUTS, they realized dynamical modeling of the passenger's behavior and route choice, and transit demand prediction on a simplified transit network. The demonstration system of the Beijing AUTS was also presented in their paper. Zhang *et al.* [22] built the system of computational experiments and decision support for ITS, which is a complete application system of ATS. Wang and Shen [23] applied the GPU-based cloud computing technique to develop the ATS, which greatly improved the operation speed of ATS, and thus made the on-line operation of ATS become possible. Besides, ATS have also been applied in other sorts of transportation systems, e.g. urban rail transportation systems [24], [25] and high-speed railway systems [26].

V. CONCLUSIONS

This paper has shown an overview of Artificial Transportation Systems (ATS) by reviewing the related literatures to date. The main contents include the theory framework, research methods, implementation approaches, and case studies. By analyzing the existing works, we can draw the following conclusions.

Since ATS were proposed almost a decade ago, many research works have been done in this field. In these research works, not only new methods of ATS were developed, but also successful real-world applications were reported for ATS. All of the research works kept on gradually enriching the theoretical system of ATS. Nevertheless, the research on ATS is still just at its beginning, and there are still many technical problems need to be explored and solved. They mainly lie in the following two aspects:

1) The construction techniques of ATS are immature:

Although the four key research methods of ATS has been widely studied for many years, for the research field of ATS, they are still quite new, especially for P2P computing and social computation theory. This sort of interdisciplinary development will play a very significant role in the construction of ATS, but still lack in-depth research and application.

2) Real-world applications of ATS need to be strengthened:

Most of the PtMS at present are only to connect the actual transportation systems and the traffic simulation systems to build the simple parallel systems, which is not completely in the sense of parallel transportation systems. Therefore, not only ATS need further be explored, finalized, and applied, but the related methods of computational experiment and parallel execution also need to be deeply investigated. In addition, more real-world practices of ATS also need to be performed in complex traffic environments.

REFERENCES

- [1] F.-Y. Wang and S. Tang, "Concepts and frameworks of artificial transportation systems," *J Complex Syst. Complexity Sci.*, vol. 1, no. 2, pp. 52-59, 2004.
- [2] F.-Y. Wang and S. Tang, "A framework for artificial transportation systems: from computer simulation to computational experiment," in *Proc. 8th IEEE Conf. Intell. Transp. Syst.*, 2005, pp. 13-16.
- [3] S. Tang, F.-Y. Wang, X. Liu, *et al.*, "A preliminary investigation on artificial transportation systems," *J. Syst. Sim.*, vol. 17, no. 3, pp. 704-709, 2005.
- [4] C. H. Builder and S. C. Bankes, "Artificial societies: a concept for basic research on the societal impacts of information technology," 1991, Rand Report P-7740.
- [5] S. Tang and F.-Y. Wang, "A preliminary study for basic approaches in artificial transportation systems," *J. Grad. Sch. Chinese Academy Sci.*, vol. 23, no. 4, pp. 569-575, 2006.
- [6] F.-Y. Wang, R.-W. Dai, S. Tang, *et al.*, "A complex systems approach for studying integrated development of transportation, logistics, and ecosystems," *J. Complex Syst. Complexity Sci.*, vol. 1, no. 2, 2004.
- [7] Q. Miao, S. Tang, and F.-Y. Wang, "Design of artificial transportation system based on JXTA," *J. Transp. Syst. Eng. Inf. Tech.*, vol. 6, no. 6, pp. 83-90, 2006.
- [8] Q. Miao, Z. Wang, F.-Y. Wang, S. Tang, and F. He, "An implementation of artificial transportation systems based on JXTA," in *Proc. IEEE Int. Conf. Veh. Electron. Safety*, 2006, pp. 93-97.
- [9] J. Li, S. Tang, X. Qin, *et al.*, "Growing artificial transportation systems: a rule-based iterative design process," *IEEE Trans. Intell. Transp. Syst.*, vol. 12, no. 2, pp. 322-332, 2011.
- [10] Q. Miao, F. Zhu, Y. Lv, *et al.*, "A game-engine-based platform for modeling and computing artificial transportation systems," *IEEE Trans. Intell. Transp. Syst.*, vol. 12, no. 2, pp. 343-353, 2011.
- [11] F. Zhu, Z. Wang, F.-Y. Wang, and S. Tang, "Modeling interactions in artificial transportation systems using Petri net," in *Proc. 9th Int. IEEE Conf. Intell. Transp. Syst.*, 2006, pp. 1131-1136.
- [12] F.-Y. Wang and S. J. Lansing, "From artificial life to artificial societies: new methods in studying social complex systems," *J. Complex Syst. Complexity Sci.*, vol. 1, no. 1, pp. 33-41, 2004.
- [13] H. Zhang, Q. Yu, J.-G. Liu, and J. Rong, "Application of parallel systems theory in traffic engineering," *J. Traffic Inf. Safety*, vol. 27, no. 1, pp. 32-35, 2009.
- [14] F.-Y. Wang, "Parallel control and management for intelligent transportation systems: Concepts, architectures, and applications," *IEEE Trans. Intell. Transp. Syst.*, vol. 11, no. 3, pp. 630 - 638, Sep. 2010.
- [15] F.-Y. Wang, "Computational experiments for behavior analysis and decision evaluation of complex systems," *J. Syst. Sim.*, vol. 16, no.5, pp. 893-898, 2004.
- [16] F.-Y. Wang, "Parallel systems for management and control of complex systems," *J. Control Decision*, vol. 19, no. 3, pp. 485-490, 2004.
- [17] Y. Lv, Y. Qu, S. Tang, *et al.*, "Computational experiments of evaluating road network traffic conditionals based on artificial transportation systems," *J. Jilin Univ. (Eng. Tech. Ed.)*, vol. 39, no. 2, pp. 87-90, 2009.
- [18] F. Zhu, D. Wen, and S. Chen, "Computational traffic experiments based on artificial transportation systems: an application of ACP approach," *IEEE Trans. Intell. Transp. Syst.*, vol. 14, no. 1, pp. 630-638, Mar. 2013.
- [19] G. Xiong, X. Dong, D. Fan, *et al.*, "Parallel traffic management system and its application to the 2010 Asian Games," *IEEE Trans. Intell. Transp. Syst.*, vol. 14, no. 1, pp. 630-638, Mar. 2013.
- [20] R. Li, J. Zhong, and F. Zhu, "On computational experiment in the parallel public transportation system," *ACTA AUTOMATICA SINICA*, vol. 39, no. 1, pp. 1-7, Jan. 2013.
- [21] L. Li, H. Zhang, X. Wang, *et al.*, "Urban transit coordination using an artificial transportation system," *IEEE Trans. Intell. Transp. Syst.*, vol. 12, no. 2, pp. 374-383, Jun. 2011.
- [22] N. Zhang, F.-Y. Wang, F. Zhu, *et al.*, "DynaCAS: Computational experiments and decision support for ITS," *IEEE Intell. Syst.*, vol. 23, no. 6, pp. 19-23, Nov./Dec. 2008.
- [23] K. Wang and Z. Shen, "Artificial societies and GPU-based cloud computing for intelligent transportation management," *IEEE Intell. Syst.*, vol. 26, no. 4, pp. 22-28, Jul./Aug. 2011.

- [24] B. Ning, F.-Y. Wang, H. Dong, *et al.*, "Parallel systems for urban rail transportation based on ACP approach," *J. Transp. Syst. Eng. Inf. Tech.*, vol. 10, no. 6, pp. 22-28, 2010.
- [25] B. Ning, H. Dong, D. Wen, *et al.*, "ACP-based control and management of urban rail transportation systems," *IEEE Intell. Syst.*, vol. 26, no. 2, pp. 84-88, Mar./Apr. 2011.
- [26] B. Ning, T. Tang, H. Dong, *et al.*, "An introduction to parallel control and management for high-speed railway systems," *IEEE Trans. Intell. Transp. Syst.*, vol. 12, no. 4, pp. 630 - 638, Dec. 2011.