Parallel Bus Rapid Transit (BRT) Operation Management System Based on ACP Approach

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***Abstract*—Bus Rapid Transit (BRT) is an effective way to increase urban traffic capacity. But its operation and scheduling optimization are difficult. In this article, Parallel BRT Operation Management System (PBOMS) is constructed based on ACP approach. It can detect the passenger's quantity on station platforms in real-time, traffic flow besides stations or at intersections, and the queuing length of vehicles on the road lines. It can provide short-term passenger and traffic saturation prediction in order to arrange transportation management more accurately to relieve the congestion. It can assess, improve and optimize the emergency management during holidays, public events, accidents and other emergency situations. It can improve the quality of real-time scheduling functions by using the measurement results detected from traffic videos, and so on. This system has been piloted in Guangzhou Zhongshan Avenue BRT, which was applied for BRT's monitoring, warning, forecasting, emergency management, real-time scheduling and other purposes, to improve Guangzhou BRT's smoothness, safety, efficiency and reliability.**

Keywords-bus rapid transit (BRT); ACP approach; parallel system; bus dispatch; intelligent monitoring

I. Introduction

Since the 1970s, as economic development and per capita income level improve, motor vehicle ownership in every country is increasing rapidly, which has caused serious traffic congestion, traffic accidents, energy crisis, shortage of land resources, environment deterioration and air pollution[1]. Urban development needs the support of public transport systems. But, the railway system, because of the huge investment and the difficulty to cover a large area in the limited time, has many limitations. And regular bus systems also have many functional limitations, like low operational efficiency and poor level service, etc. [2-4].

Bus Rapid Transit (BRT), a novel type and high efficient bus operator system and a comprehensive mass transit system between the metro and regular bus systems, whose transportation speed and capacity is close to the rail transportation, and whose cost is close to the general bus, is becoming more popular and welcome in many cities [1,2]. BRT has been found one of public transport systems with the most economic and efficient advantages in the world, and it can quickly build public transport system and form a complete network, and can also provide fast and high-quality services.

Since the first BRT route in the world was built up in Curitiba, Brazil, 1973, BRT has already become popular all over the world quickly, and get much supports from large and international financial organizations such as UN-Habitat, International Energy Agency, International Association of Public Transport, Institute for Transportation and Development Policy, United Nations Development Program, World Bank, Asian Development Bank, Central America Development Bank, Global Environment Facility, and so on. Currently, BRT systems are being planned and implemented in many cities in the world [1, 5-6]. There are more than 100 cities in the world which have built BRT.

But, because of its complexity, BRT's operation management and scheduling is very difficult, and the existing scheduling and management are executed mainly with the operator's experiments, which limit BRT's efficiency and benefit, and its competitiveness compared to regular bus, metro and light rail. So, new theory and methods are required to research BRT.

ACP approach, which is based on holism, can provide a new way of thinking to solve the modeling, operations management and control of complex systems, and has its specific advantages in the research on complex urban transportation system.

In this article, ACP approach is applied to build up Parallel BRT Operation Management System (PBOMS) based on the existing traffic video detection and traffic management systems of the BRT system in Guangzhou. The system can meet monitoring, alarm, forecasting, emergency management, real-time scheduling and other needs of the Guangzhou BRT, and to make it smooth, safe, efficient and reliable.

II. Brief Introduction of BRT

Bus Rapid Transit is a flexible, high performance, rapid transit mode that combines such elements as exclusive right-of-way, specifically designed stations, operation systems, customer service systems and Intelligent Transportation Systems (ITS), to offer a reliable, speedy, comfortable and low-cost service [1]. BRT can be the main part of transportation system or as a complement, extension or substitute for urban rail transportation

BRT is a flexible, rubber-tired rapid-transit mode that

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combines vehicles, stations, running ways, fare, ITS and services elements into an integrated system with a strong positive identity that evokes a unique image [1,2,5-10].

1) BRT vehicles

BRT vehicles are usually uniform with bright colors to be identified easily and to show the brand effect of BRT system. Vehicles with lower floor are more convenient for passenger alighting and boarding. The use of advanced articulated buses as long as 18-25m which could accommodate 200-250 persons is to increase the capacity and reduce the average operate cost. BRT systems in many cities are considered as the low-emission and low-noise buses which have little influence or pollution on the environment [5]. Different capacity buses can be chosen for different lines according to their specific requirements or conditions.

2) Stations and intermodal terminal

The design of stations takes its safety, comfort and closure into account. The stations are equipped with automatic ticketing and fare collection system outside the vehicles, Variable Message Signal (VMS) and operating information system. The station platforms are the same high level as the vehicles floors to allow passengers' convenient alighting and boarding. And the stations also have a quality image and unique identity or significant architectural features to make them different from the normal stations, to facilitate the identification of passengers [6].

3) BRT corridors

BRT vehicles operate on their dedicated bus corridors to keep their speed, and avoid from the impact of congestion. BRT corridors are the most critical element to determine the speed and reliability of BRT services. Operating speed is 20-35km/h, close to the speed of the urban rail. And in the intersections, BRT vehicles have priority right of traffic lights to contribute for their operating speed [7].

4) Fare collection

BRT system includes an integrated fare collection system of a ticketless system, magnetic strip technology, and smart cards which are similar to the subway or light rail. Pre-board fare collection is used to allow for simultaneous alighting and boarding. In the station, passengers can select the bus lines freely. All these solutions can reduce the passengers' time consumption of buying tickets and getting on, passengers' waiting time and vehicles' dwelling time [1].

5) ITS application

ITS can improve operation management and vehicle control, and can replace some functions provided by expensive physical infrastructure which is difficult to maintain, or other types of rapid transit. They can be used to convey passenger information in a variety of venues, monitors, or control bus operations, provide priority at signalized intersections, enhance the safety and security on board vehicles and at stations, and even provide guidance for BRT vehicles [8-11].

6) Service plan and operation organization

BRT system usually can provide all-day, high frequency service. Service lines and schedules can be adjusted according to the season, date and time to meet different needs of passengers [12, 13]. The accidents, emergencies and other situations can be deal with in time.

Figure 1. BRT in Guangzhou China (from www.chinabrt.org)

III. Difficulty of BRT's Operation and Scheduling

A. BRT's Operation and Scheduling

BRT's operation and management is very important to ensure BRT's competitiveness priority to regular bus and metro. But, BRT's current research focuses on the planning and construction, such as BRT's development, network planning, engineering, etc., while the research of operation, management and scheduling optimization is still insufficient.

Currently, the shortage of BRT's operation management and scheduling includes:

- BRT's scheduling is optimized and adjusted mainly by personal experience based on the historical OD data. It is short of effective prediction of traffic and passenger, and evaluation methods and scheduling is still static, not real-time, and more difficult to forecast information.
- BRT vehicles operation and passenger demand information can't be automatically measured, and is still got through manually counting, so it is difficult to apply in a wide range. The vehicles emergency scheduling and timely adjustments is difficult.
- BRT is usually supported by ITS, such as GPS, GIS, and intelligent scheduling system, etc., by which BRT can real-time monitor BRT vehicles' operations, data transmission and intelligent scheduling, to improve the efficiency of dispatching operations. But the current study can't combine intelligent scheduling of BRT with ITS well together.
- BRT's scheduling is influenced by such factors as passengers, vehicles, and roads, involving engineering complexity factors, social complexity factors and other aspects. The conventional methods are difficult to build its models. Novel theories and methods are needed.

In this article, based on ACP approach, artificial BRT system is built. By combining actual BRT system and its video system, PBOMS can be built to achieve BRT's intelligent monitoring and optimized scheduling.

B. ACP Approach and Its Application

ACP approach, mainly consisting of artificial systems(A), computational experiments(C), and parallel execution(P), which is based on holism and complex system theory, has its specific advantages in the modeling, operation and management of complex system. By considering all factors such as engineering, society, human and environment factors, ACP approach combines theoretic modeling, experience modeling and data-driven model, to solve the traditional modeling difficulty of complex actual systems. The interaction relationships among actual systems' various factors and their evolution laws under normal and abnormal conditions can be studied by computing experiments or "trial" based on their artificial systems [9]. The reactions of actual system and artificial system can be compared and analyzed through their connection, and "reference" and "estimation" of their future status can be studied, then their control and management methods can be adjusted accordingly. Finally, parallel execution can be achieved to optimize the control of actual systems and reduce the occurrence possibility of abnormal situation via the results of computational experiments [12-15].

At present, ACP approach already has its basic shape, and its theory and technology are becoming enriched. ACP approach has successfully applied in the control and management of Emergency Management [11], traffic system [12-20], ethylene production [21], and are being applied in agriculture, military, logistics, economic, security, management and other fields. More and more academic researchers and industrial engineers are applying ACP approach.

IV. PBOMS BASED ON ACP APPROACH

Based on ACP approach, firstly, the multi-modal combination method, is researched to merge data modeling, conventional mechanism modeling and expertise modeling, and Parallel BRT Operation Management System PBOMS, See Figure 2 is built based on the existing artificial transportation systems (TransWorld) and the related data and of BRT system in Guangzhou. It can achieve monitoring, alarm, forecasting, emergency management, real-time scheduling and other needs for management center. It can real-time monitor, alarm, and forecast passengers at stations, and station traffic, channel traffic, traffic flow at intersections and vehicle queue. It can assess, improve, and optimize emergencies emergency management for holidays, major activities, and accidents. It can achieve real-time scheduling based on video detection results. It can collaboratively optimize BRT's passengers, vehicles, and roads through parallel execution.

Secondly, BRT evaluation indexes structure is established, comprehensively considering operational efficiency, service levels, passenger satisfaction, and emergency response capability, etc.

Thirdly, based on artificial BRT system and BRT evaluation indexes system, BRT's collaborative evaluation rules among its passengers, vehicles, and roads in different time and space areas are simulated and analyzed by orthogonal computing experiments, random computing experiments or other computing experiments.

Finally, via these rules, collaborative optimization methods, policies, regulations and emergency plan optimization of passenger flow and vehicle stream, vehicle stream and intersections can be researched.

This research can help BRT managers and companies to achieve active management, improve operational efficiency, emergency management and service level, and improve the level of BRT planning and design.

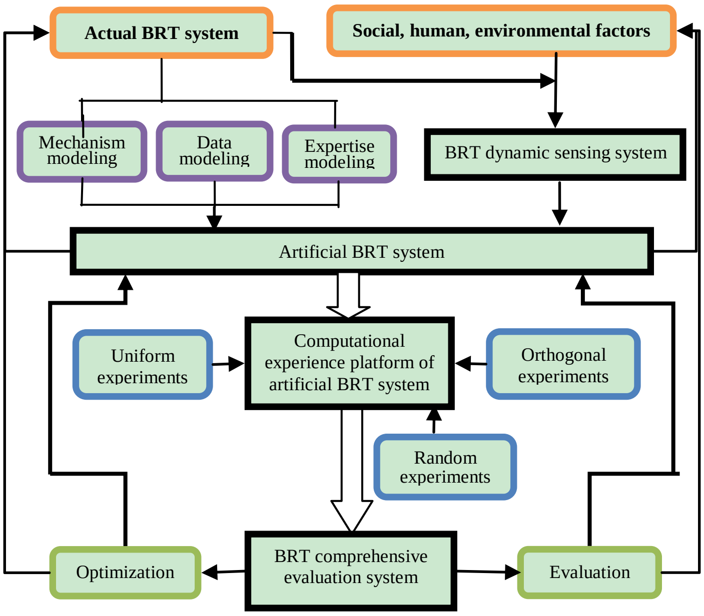

Figure 2. The diagram of PBOMS

PBOMS includes BRT dynamic sensing system, artificial BRT system, BRT comprehensive evaluation system, computational experiments platform of artificial BRT system.

A. BRT Dynamic Sensing System

BRT Dynamic sensing system can integrate videos in vehicles, at stations, and at intersections with GPS and GIS together to grasp the spatial and temporal distribution of passenger flow, and to achieve real-time transmission, real-time monitoring, real-time scheduling, real-time information distribution and other features, which can make BRT operators to master real-time the operation situation of BRT vehicles, stations conditions and status in vehicles, to provide data to support the scheduling decision-making for leadership and control center, to implement BRT safe, reliable, efficient operation, to achieve BRT's largest political, economic, social and environmental benefits. To achieve BRT's optimal scheduling, the vehicles' location, pull in and out time at stations, waiting passenger number at stations, passenger number inside the vehicles is needed. At the same time, road signal control system also needs to obtain the exact location of the vehicles to make them have priority right of traffic lights.

B. *Artificial BRT System*

BRT includes passengers, vehicles, roads, environment, management and other factors, involving engineering complexity and social complexity. The traditional traffic models, expertise models, mathematical models, or actual operational data model are all incomplete, so multi-modal modeling approach is needed to compensate each other. In this article, based on ACP approach, an artificial BRT system is built. In general, "vehicles", "roads" and other complex objects are modeled by mechanism modeling approaches, "passengers" and "environment" and other social complexity objects are modeled by Agent modeling, complex objects are modeled by expertise model (neural network), and the others are modeled by the BRT data modeling (Monte Carlo model).

Artificial BRT system is to "cultivate" or "grow" actual BRT’s "alternative" version in artificial virtual environment to provide an open and highly reliable test platform. Artificial BRT system is composed of four elements: passengers, vehicles, roads and environment, which has open data interfaces and models which can access the existing network structure and population distribution database. It is based on the individual agent technology modeling, then every individual is represented by a certain independence and unification intelligent agent who has an independent individual characteristics, and whose intelligence and initiative is mainly reflected in the completion of the process activities and trips in the individual model. Artificial BRT system can take full advantage of existing traffic simulation models to "emerge" generation of complex transport phenomena through a large number of individual traffic behaviors.

The system uses artificial transportation system (TransWorld) developed by CASIA (Institute of Automation, Chinese Academy of Sciences), as the kernel of artificial BRT system. This system can provide the design platform of artificial transportation system, through the platform, the elements of artificial transportation systems can be reconfigured to build the artificial system which the designers need.

Artificial BRT system includes basic information module, road network module, transport vehicle module, travel behavior module, path planning module, micro-simulation traffic module, etc. Among them, basic information module is its most basic part, which includes:

- BRT stations information: name, position, number of substation, substation length, uplink or downlink, etc.
- BRT channel (between adjacent two stations) information: name, position, length, etc.
- BRT intersections information: name, position, channel, traffic signal setting, etc.
- BRT lines: name, stop stations, bus number, stop substation, vehicle number, etc.
- BRT vehicles information: plate numbers, GPS code, lines, operation or not, uplink or downlink, operation mode (whole bus, short U-turn bus, shuttle bus, express, etc.), position, position, velocity, etc.
- BRT management center: rules and regulations、scheduling scheme, departure timetable, etc.
- Related personnel information: passenger, drivers and crew members, manager, etc.
- Environment information: environment, transport facilities, etc.
- Others information: company benefits, social benefits, passenger satisfaction, vehicle scheduling, personnel scheduling, etc.

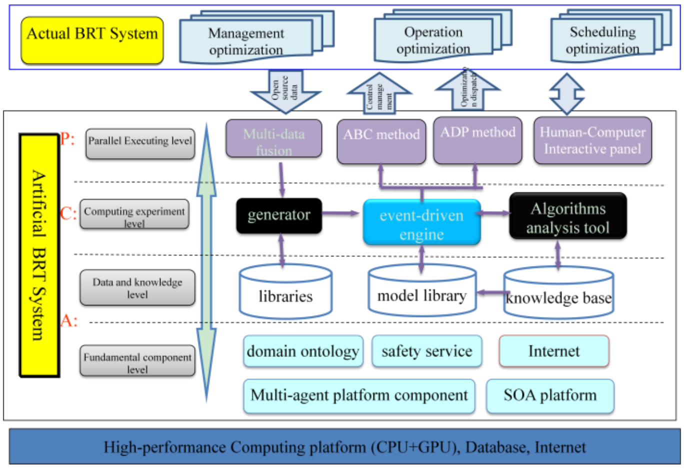

Figure 3. Artificial BRT System

C. *BRT Comprehensive Evaluation System*

Comprehensively considering stations, lines, and region, multi-level multi-objective BRT comprehensive evaluation system can be established, which can comprehensively evaluate BRT's technical, economic, environmental, social and urban development, the coordination among passengers, vehicles, roads, and stations, policies, regulations and other rules and regulations, and emergency management and assessment by fuzzy comprehensive evaluation method: analyzing quantitative indicators by analytic hierarchy process, analyzing qualitative indicators by expert analysis process, and dimensional transformation into a unified. This system can analyze and evaluate the operation results of actual BRT system and computation experiments results of artificial BRT system to reflect the performance of key aspects of BRT operation.

D. *Computational Experiments Platform of Artificial BRT System*

The computational experiments platform of Artificial BRT System is a scene generator which can support real and virtual experimental scene simultaneously. It can accept the scenarios inputted by end-users or specific scenarios in the libraries automatically, and instantiate their interaction mechanisms and rules, and pass then to the event-driven calculation engine to complete computational experiments. Based on discrete event simulation technology, event-driven engine can be achieved, and the interaction and communication process can be dynamically simulated in scenarios. The event-driven simulation engine can simulate clock time at a specific time by simulation clock platform, and store the information in chronological order, and analyze and determine the triggered relations among discrete events and events in the course of the experiment. The experimental process can be promoted and driven by simulation clock and the handling of discrete event. The computing algorithm analysis tools, such as various groups' strategy learning and optimization algorithms, qualitative and quantitative assessment algorithms of computational experiments, and specific algorithms modules to provide support for various applications areas, can be used in the experimental platforms as the form of modules and components. These tools can dynamically analyze, evaluate, and optimize process and results of computational experiments and update real-time knowledge base.

The computational experiments platform can support its design, implement, prediction, and analysis of computational experiments based on its Artificial BRT System, to set different control strategies and command system and other configuration of passenger flow, vehicle flow, and intersections, to get different "scenarios" on Artificial BRT System, to form the plans of uniform experiments, orthogonal experiments, and random experiments.

Through different experimental design based on Artificial BRT System, a large variety of computational experiments can be implemented, and a variety of comprehensive, accurate and quantitative results of BRT's collaborative optimization evaluated in different indicators system can be gotten. "Computational experiments" include BRT service levels, accident rates, waiting time, economic constraints, environmental damage, resource consumption, and the impact of population, a variety of traffic rules and regulations, laws and regulations, BRT line network optimization and dispatching, and emergency management plans for emergencies or major events, and so on.

E. A Case Study

PBOMS combines the actual BRT, BRT dynamic sensing system, artificial BRT system, BRT comprehensive evaluation system, and the computational experiments platform of Artificial BRT, which can achieve BRT collaborative optimization of passengers, vehicles and roads such as "interaction between virtual system and actual system, active management, rolling optimization". At the same time, it can achieve real-time flow monitoring at stations and in vehicles and vehicle flow in roads and at stations. It can meet the requirements in Guangzhou City such as monitoring, alarm, emergency management, real-time scheduling, to achieve real-time monitoring, alarm of passengers at stations, traffic flow at stations, channel traffic flow, traffic flow and vehicles queuing at intersections or stations for BRT Management Center at the stations (see Figure 4). Based on real-time monitoring data, the data of passenger and traffic changes in the following time can be predicted to provide decision support for the optimal operation and scheduling of BRT. Figure 5 displays the comparison of frequency of Line B1 in Guangzhou BRT before and after the application of this system. It can be seen from the figure, total number of the departure decreases from 144 to 133, and the morning and evening peak density are increased, and the waiting time of the bus passengers is reduced. In normal period, appropriate reduction of the departure density according to the number of passengers waiting at stations can lower the bus company's operating costs resulting in less impact on passengers.

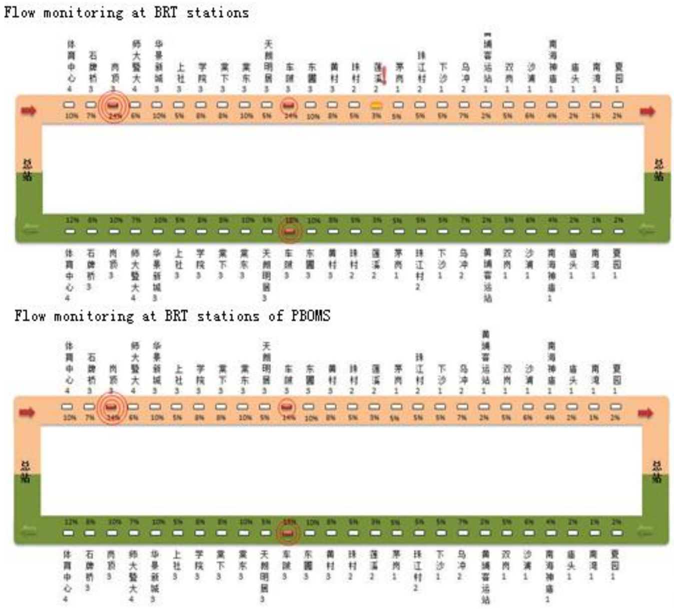

Figure 4. Passenger flow monitoring at BRT stations and its forecast based on PBOMS

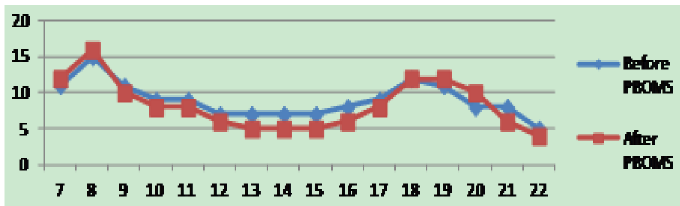

Figure 5. The frequency change of Line B1 before and after PBOMS

V. CONCLUSIONS

Based on ACP approach to combine the existing traffic video detection of Guangzhou BRT with artificial transportation system, Parallel BRT Operation Management System, which mainly includes artificial BRT system, BRT's dynamic sensing system, BRT comprehensive evaluation system, computational experiments platform of artificial BRT system, is built, to help BRT management center to real-time detect the passenger's quantity at stations platform, traffic flow at stations or at intersections, and the queuing length of vehicles on the road. It can provide short-term passenger and traffic saturation prediction in order to timely arrange transportation management and relieve congestion. It can assess, improve and optimize the emergency management of holidays, events, accidents and other emergencies. It can improve the quality of real-time scheduling functions by using the measurement results detected from traffic videos, and so on.

This system has been piloted in Guangzhou Zhongshan Avenue BRT, which was applied for BRT's monitoring, warning, forecasting, emergency management, real-time scheduling and other needs, to improve Guangzhou BRT's smoothness, safety, efficiency and reliability.

REFERENCES

[1] L. Wright, and W. Hook, Bus Rapid Transit (BRT) Planning Guide, Institute for Transportation and Development Policy (ITDP), 2007.

[2] America Federal Transit Administration. Bus Rapid Transmit Offers Communities a Flexible Mass Transit Option. 2003.

[3] F. Y. Wang, "Toward a paradigm shift in social computing: the ACP approach," *IEEE Intelligent Systems,* vol. 22(5, pp. 65-67, 2007.

[4] F. Y. Wang, "Artificial Societies, Computational Experiments, and Parallel Systems: An Investigation on Computational Theory of Complex Social-Economic Systems," *Complex Systems and Complexity Science*, vol. 1, no. 4, pp. 25-35, 2004.

[5] P. K. Mzee, and C. Yan, "Implementation of BRT system in developing countries as the best option in reducing emission the case study of Dart system in Dar es Salaam," *IEEE International Conference on Advanced Management Science*, vol. 2, pp. 532-537, 2010.

[6] C. H. Zhou, and Z. G. Gao, A Real-Time Information System for BRT Based on GPS/Signpost Compound Navigation Technology," *International Conference on Logistics Engineering and Intelligent Transportation Systems*, pp. 1-4, 2010.

[7] Z. B Peng, and X. Xie, "Guidance algorithm of the BRT vehicles anchor the station based on fuzzy control theory," *7th International Conference on Fuzzy Systems and Knowledge Discovery*, vol. 1, pp. 196-198, 2010.

[8] Y. Zhu, "Study on Intelligent Traffic Control Based BRT," *2nd International Workshop on Intelligent Systems and Applications*, pp. 1–4, 2010.

[9] D. He, G. Q. Yan, and Y. Ma, "Study of Bus Rapid Transit System Evaluation Based on Gray Extension Matter-element Model," *International Conference on Intelligent Computation Technology and Automation*, vol. 1, pp. 1125-1128, 2011.

[10] F. Y. Wang, "Parallel control and management for intelligent transportation system: concepts, architectures and application." *IEEE Transactions on Intelligent Transportation Systems*, vol. 11, no. 3, pp. 1-10, 2010.

[11] F. Y. Wang. "Systemic framework of PeMS (Parallel emergency management system) and its applications." *Chinese Emergency Management*, vol. 12, pp. 22-27, 2007.

[12] G. Xiong, K. F. Wang, F. H. Zhu, et al. Parallel traffic management for 2010 Asian Games. IEEE Intelligent Systems, vol. 24, no. 5, pp. 81-85, 2010.

[13] S. M. Tang, and F. Y. Wang, "A Preliminary Study for Basic Approaches in Artificial Transportation Systems." *Journal of the Graduate School of the Chinese Academy of Sciences*, vol. 23, no. 4, pp. 569-575, 2006.

[14] F. Y. Wang, and S. M. Tang. "A framework for artificial transportation systems: From computer simulations to computational experiments," *IEEE Conference on Intelligent Transportation Systems*, pp. 1130-1134, 2005.

[15] J. Y. Li, S. M. Tang, X. Q. Wang, et al. "A Software architecture for artificial transportation systems-principles and framework." *10th IEEE International Conference on Intelligent Transportation Systems*, pp. 229 -234, 2007.

[16] F. He, Q. H Miao., Y. T. Li, et al. "Modeling and analysis of artificial transportation system based on multi-agent technology." *IEEE Conference on Intelligent Transportation Systems*, pp. 1120-1124, 2006.

[17] J. Y. Li, S. M. Tang, and F. Y. Wang, "An Investigation on ATS from the Perspective of Complex Systems," *11th IEEE International Conference on Intelligent Transportation Systems*, pp. 20-24, 2008.

[18] Q. H. Miao, F. H. Zhu, Y. S. Lv, et al. "A Game-Engine-Based Platform for Modeling and Computing Artificial Transportation Systems," *IEEE Transactions on Intelligent Transportation Systems*, vol. 12, no. 2, pp. 343-353, 2011

[19] L. F. Li, H. Zhang, X. F. Wang, et al. "Urban Transit Coordination Using an Artificial Transportation System," *IEEE Transactions on Intelligent Transportation Systems*, vol. 12, no. 2, pp. 374-383, 2011.

[20] F. Y. Wang, and S. M. Tang, "Concepts and Frameworks of Artificial Transportation Systems," Complex Systems and Complexity Science, vol. 1, no. 2, pp. 52-59, 2004.

[21] G. Xiong, F. Y. Wang, Y. M. Zou, C. J. Cheng, and L. F. Li. "Parallel evaluation method to improve long period ethylene production management", Control Engineering, vol. 13, no. 3, pp. 401-406, 2010.