Short Paper

Parallel Public Transportation System and Its Application in Evaluating Evacuation Plans for Large-Scale Activities

Fenghua Zhu, Songhang Chen, Zhi-Hong Mao, and Qinghai Miao

***Abstract*—This paper proposes a method based on the Artificial societies, Computational experiments, and Parallel execution (ACP) approach to build parallel public transportation systems (PPTSs). The framework and components of a PPTS are analyzed, and some details for building the PPTS are discussed. One prototype based on intelligent traffic clouds is established. One specific PPTS is developed for the Guangzhou 2010 Asian Games in the case study, and its effectiveness is verified through the evaluation of two evacuation plans for the Asian Games.**

***Index Terms*—Artificial transportation system, computational experiment, parallel public transportation system (PPTS), transportation evacuation.**

I. Introduction

With the rapid development of economy, more and more large-scale activities, such as sport games, concerts, and exhibitions, are held all over the world, particularly in big cities. Taking China as an example, it has hosted a series of big events in recent years: the Beijing 2008 Summer Olympic Games, the Shanghai 2010 World Exhibition, the Guangzhou 2010 Asian Games, etc. To guarantee the success of these activities, public transportation management for evacuation is one of the priority problems to be addressed.

Public transportation management not only serves for people's daily activities, such as work and school, but also plays an important role in some special activities. Large-scale activities often lead to massive pedestrian and vehicle flows in limited space within a short period of time. These traffic flows exhibit notably different characteristics when compared with daily flows. For example, the traffic flows usually accumulate to large volumes in the short periods before and after a large-scale activity; the categories and attributes of participants can be predicted according to the nature of the activity; private vehicles may be prohibited in the surrounding area of the activity; and most participants need to be evacuated by public transportation in a short period of time.

Generally, the public transportation management in a large-scale activity must satisfy two types of demands, i.e., the demands induced by the activity itself and those induced by people's daily activities, respectively. The latter has been studied intensively [1]–[7], whereas the former attracts little research attention. Our paper focuses on the former demand, i.e., the demand by a large-scale activity. In a large-scale activity, there are various types of participants requiring different traffic services. To keep the evacuation process quick, safe, orderly, and friendly is the main goal of public transportation scheduling in a large-scale activity. Furthermore, considerations include balancing the interests of passengers, transportation companies, and social environment, and maximizing the integrated benefit.

Most existing studies on traffic management and control still rely on traditional theories and tools of transportation engineering, which are based on the description of phenomena rather than the analysis of principles and are focused on control and traffic rather than service and people. All these lead to three deficiencies of current transportation management and service, i.e., lacking efficient coordination and management for the planning and operation of different travel modes, lacking sufficient supervision and control of traffic elements, and lacking optimal design and execution of traffic service utilizing intelligent transportation systems (ITSs). Therefore, there is an urgent need to study the people-oriented management and service of intelligent transportation, which benefits from a promoted understanding of travelers' behaviors.

Recent advancements in complex systems and computational intelligence have brought new perspectives and insights into the study of intelligent traffic control and management, and provided us with new tools and integrated approaches at the system level. The Artificial societies, Computational experiments, and Parallel execution (ACP) approach was originally proposed in [8] and [9] as a coordinated research and systematic effort with emerging methods and techniques to model, analyze, and control complex systems. This approach consists of three steps, i.e., representation with Artificial society models, analysis and evaluation by Computational experiments, and control and management through the Parallel execution of real and artificial systems.

The ACP approach differs from traditional methods in that it integrates theoretical analyses, scientific experiments, and computational technologies. The ACP approach can make sufficient use of traffic information, consider both control and service functions, and realize the people-oriented management of transportation. By adding the control and management functions of social elements, the ACP-based parallel transportation systems can not only improve our cognitive competence in the dynamic formation and evolution mechanism of transportation systems but also optimize the control and management process of the system in both normal and abnormal conditions.

Now, pioneering works have been accomplished in many areas that are related to the parallel transportation systems theory and

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F. Zhu and S. Chen are with the State Key Laboratory for Management and Control of Complex Systems, Institute of Automation, Chinese Academy of Sciences, Beijing 100190, China (e-mail: fenghua.zhu@ia.ac.cn; songhang.chen@ia.ac.cn).

Z.-H. Mao is with the Department of Electrical and Computer Engineering and the Department of Bioengineering, Swanson School of Engineering, University of Pittsburgh, Pittsburgh, PA 15260 USA (e-mail: maozh@engr.pitt.edu).

Q. Miao is with the Department of Computing and Communication Engineering, College of Engineering and Information Technology, University of Chinese Academy of Sciences, Beijing 100049, China (e-mail: miaoqh@ucas.ac.cn).

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verification, e.g., traffic signal control, public transportation management, etc. The focus of this paper is to present our work of applying the ACP approach in the public transportation management for large-scale activities, i.e., the modeling and analysis of parallel public transportation systems (PPTSs).

The rest of this paper is organized as follows. Section II proposes the framework of a PPTS, and Section III discusses how to implement the system on ITS clouds. Section IV validates the proposed method through a case study for the Guangzhou 2010 Asian Games, and Section V concludes this paper.

II. Framework of PPTS

In addition to the scheduling and monitoring functions in daily operation, public transportation management faces many operational demands. These demands include evaluating the evacuation plan before actual operation, preparing emergency plans for possible incidents, etc. To address these demands, many experiments need to be carried out, which are costly and sometimes even impossible in a real public transportation system. An artificial public transportation system (APTS) can "grow" live traffic processes in a bottom-up fashion and provide alternative versions of actual traffic activities, thus offering us a platform or a "living traffic lab" for public transportation analysis and evaluation [8], [10]–[12]. Based on an APTS, we can conduct computational experiments of a traffic signal priority plan and a vehicle schedule plan. Furthermore, by integrating environmental factors, such as economic development, adverse weather, etc., these experiments can be designed and implemented from a holism perspective; therefore, reasonable results can be guaranteed [13]. This is the basic idea of the PPTS.

Because there is no accurate mathematical model for a transportation system, the PPTS (consisting of both real and artificial transportation systems) uses agent-based technologies to establish the APTS, which models the actual public transportation system. With the APTS, we can explore the evolution rules and interactions among the elements in an actual public transportation system through computational experiments. Then, by connecting the actual and artificial systems, we can compare and analyze the behaviors of the two systems under both normal and abnormal conditions, predict the future status of the systems, and adjust the control and management methods [14], [15]. Finally, parallel execution can be achieved using the explored rules. On one hand, the operation of the public transportation system can be optimized, and the incidents can be reduced in normal conditions. On the other hand, in abnormal conditions, the system can be corrected to return to normal conditions with minimal transition time and loss. Fig. 1 summarizes the framework of the proposed PPTS.

The architecture of the PPTS is composed of four layers [16], [17], i.e., the basic components layer, the data and knowledge layer, the computational experiment layer, and the parallel execution layer. In the basic components layer, distributed storage and the computation of massive data are implemented on a cloud computing platform. This layer also establishes a multiagent environment, which includes an agent management system, a distributed directory server, an agent communication channel, etc. The data and knowledge layer sets up the participants' models, environment, rules, and the mechanism of the public transportation system using agent-based technologies, and it creates a dynamic or "living" ontology to represent and organize transportation knowledge, such as methods, algorithms, regulations, and case studies.

In the computational experiment layer, a scene generator is designed to support both real and virtual experiments. An event-driven engine is implemented based on discrete-event simulation technology. The interaction of agents is simulated dynamically, and algorithm analysis

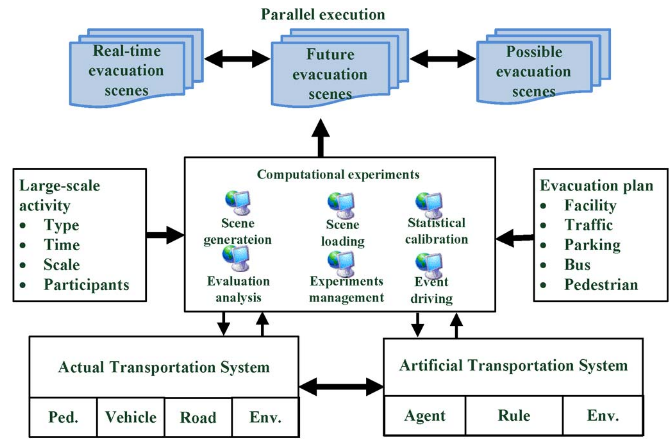

Fig. 1. Framework of the PPTS.

tools are developed on the computational experiment platform. Thus, the experimental processes and results can be analyzed, evaluated, and optimized, and the knowledge base is renewed in real time accordingly. Two types of experiments are carried out in our implementation. One is the traffic signal control optimization. By collecting public vehicle and social vehicle information, and passenger information around the intersection using intelligent perception technologies, the optimized traffic control signal plan can be verified in real time, and the maximum traffic efficiency can be achieved. The other type of experiments is the intelligent scheduling of public transportation vehicles. Based on the perceived and predicted positions of public vehicles, the passengers in vehicles, and the passengers waiting at bus stations, the departure frequency and the schedule plan can be optimized on a geographic-information-system operating platform; thus, intelligent management of public transportation can be achieved.

In the parallel execution layer, the experimental scenario is generated based on real-time detected data. The software base and application protocols in the higher level are designed. These protocols serve as the interface between the experimental platform and the terminal users, and these enable the users to manage and configure experimental conditions expediently. By monitoring and estimating the danger factors in the experiment, the event security can be passively queried, and the risk can be actively evaluated. Finally, the graphical visualization human–computer interface is designed, which can demonstrate the evolution process of both actual and artificial systems, and the interactions between the two systems.

III. Implementation on Intelligent Traffic Clouds

Agent-based PPTSs can take advantage of the autonomy, mobility, and adaptability of mobile agents in handling dynamic traffic environments. However, a large number of mobile agents will lead to a complex organization layer that requires enormous computing and power resources. To overcome this challenge, we propose a prototype of a public transportation system using intelligent traffic clouds [18], [19].

Using intelligent traffic clouds, complex computing and massive data storage can be implemented on the cloud site with high performance and a low cost. An artificial transportation system that is based on cloud computing can be divided into two parts, i.e., one is the service provider and the other is the customer. All the service providers, such as the test bed of typical traffic scenes, a traffic-strategy database, and a traffic-strategy agent database, are established as Software as a Service (SaaS). The customers, such as the urban traffic managers and traffic participants, can access these services from clouds. The intelligent traffic clouds could provide traffic-strategy agents and agent-distribution maps to the traffic management systems,

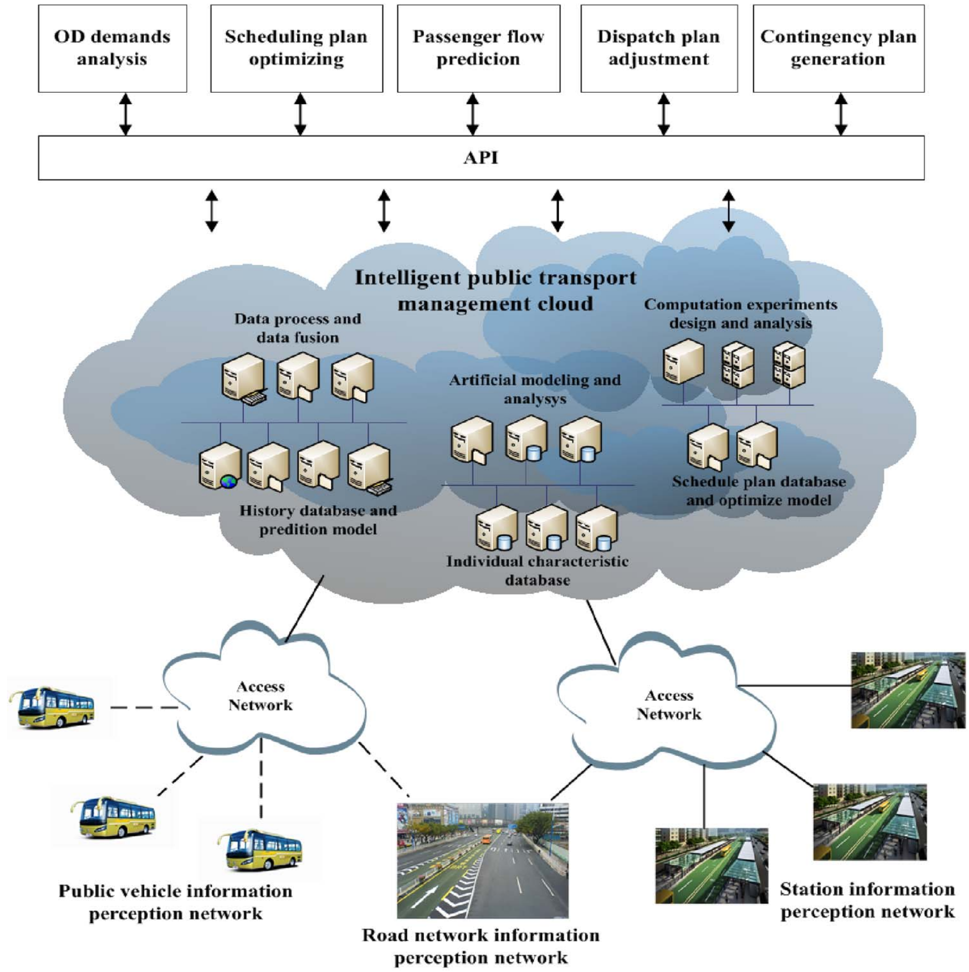

Fig. 2. Parallel transportation management system based on intelligent traffic clouds.

traffic-strategy performance to the traffic-strategy developer, and the state of urban traffic transportation and the effect of traffic decisions to the traffic managers. It could also deal with different customers' requests for services, such as storage service for traffic data and strategies, mobile traffic-strategy agents, and so on.

The prototype system is shown in Fig. 2. All services are put into the intelligent traffic clouds. In addition to transforming public vehicle schedule algorithms into schedule agents, the services also include agent performance evaluation and traffic detector data collection. Service consumers of intelligent traffic clouds include transportation managers, control algorithm developers, and transportation control centers. According to the demands of service consumers, the intelligent traffic clouds can provide the following services [20]: management services, transform services from public vehicle schedule algorithms to schedule agents, performance test and evaluation services for vehicle schedule agents, storage management services for vehicle schedule agents, storage services for operation data and detector data.

With the support of cloud computing technologies, our agent-based PPTS will go far beyond other multiagent traffic management systems, addressing issues such as infinite system scalability, an appropriate agent management scheme, reducing the up-front investment and risk for users, and minimizing the total cost of ownership.

IV. Case Study

The prototype of parallel transportation management has been employed for the 16th Asian Games in Guangzhou, China. This activity,

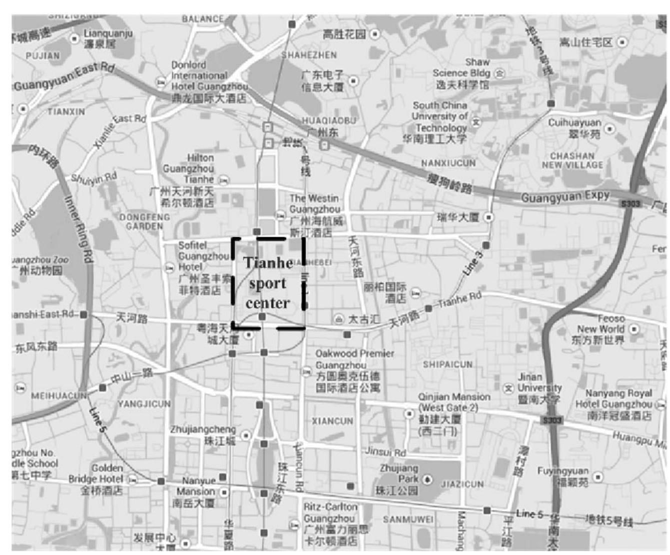

Fig. 3. Modeling area of the PPTS.

which is unprecedented in both size and scale in the 59-year history of the quadrennial event, is the largest international event held in Guangzhou and provides an important chance to promote Guangzhou's international reputation and regional economic development.

More than 10 000 athletes from 45 countries and regions participated in 42 sports, ranging from archery to chess. A large number

TABLE I
COMPETITION SCHEDULE FOR TIANHE SPORTS CENTER ON NOVEMBER 19, 2010. (M: MAN; W: WOMAN; P: PRELIMINARY; QF: QUARTERFINAL; SF: SEMIFINAL; F: FINAL)

Sport	Time	Stage	Attendance	Venue
Football	6:30PM-8:30PM	M/QF	30000~50000	Tianhe Stadium
Badminton	7:30PM-9:30PM	M/W/F	5000~7000	Tianhe Gymnasium
Water polo	9:00AM-11:10AM 2:30PM-5:10PM 7:30PM-10:10PM	M/P	3000~5000	Tianhe Natatorium
Softball	1:00PM-3:00PM 3:30PM-5:30:PM 6:00PM-8:00PM	W/P	3000~5000	Tianhe softball field
Soft tennis	9:30AM-5:00PM	M/W/SF/F	2000~3000	Tianhe tennis school
Bowling	9:00AM-12:00PM	M/W/F	<1000	Tianhe bowling hall

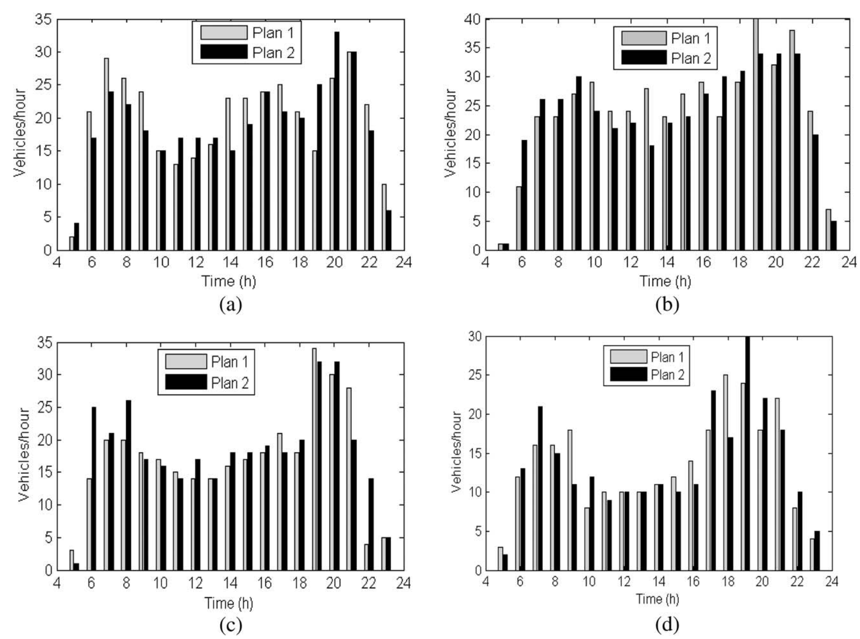

Fig. 4. BRT vehicle schedule plans for November 19, 2010. (a)–(d) Schedule plans for lines B1, B2, B3, and B4, respectively.

of contestants, spectators, and visitors can make the current congested traffic in Guangzhou even worse. Safe and effective public transportation is essential to assure the success of the games. The specific PPTS for the Guangzhou 2010 Asian Games was developed by modeling the area surrounding the Guangzhou Tianhe Sports Center (see Fig. 3). Tianhe Sports Center is one of the main venue clusters for the Asian Games. It includes six venues, i.e., Tianhe Stadium, Tianhe Gymnasium, Tianhe Natatorium, Tianhe Softball Field, Tianhe Tennis School, and Tianhe Bowling Hall. The central business district that is under construction is very near, and several shopping centers are located in the surrounding area. The public transportation facility in this area includes 2 subway lines, 30 bus lines, and 28 bus rapid transit (BRT) lines. Although many measures are taken to relieve the traffic pressures in this area, traffic flows are very high, and congestion happens frequently.

The Guangzhou municipal government pays close attention to the traffic evacuation for the competitions held in Tianhe Sports Center and regards it as one of the most important tasks in the preparation of the Asian Games. Hundreds of evacuation plans have been made by the transportation management government of Guangzhou. These plans are drawn mainly based on the managers' experiences, and their efficiency and reliability are very difficult, if not impossible, to be evaluated. The PPTS provides us one feasible way to evaluate these plans by carrying out computational experiments on artificial systems.

Public transportation is mainly modeled in two aspects, i.e., the schedule plan of buses and the arriving rate of the passengers. Here, we use two evacuation plans for the eighth day (November 19, 2010) to demonstrate the evaluation. Table I shows the competition schedule for Tianhe Sports Center in this day. Fig. 4 shows the BRT schedule plans for four lines (B1, B2, B3, and B4) in the two schedule plans.

The schedule plans are similar to the normal plan, except for the period from 19:00 to 21:00. The buses that depart between 19:00 and 21:00 have been particularly adjusted for the evacuation demand, and the vehicles are much more than the normal plan.

Computational experiments are designed and executed to grow artificial transportation scenarios on November 19, 2010. A lot of traffic parameters are collected in the experiments, and they are analyzed to generate quantitative evaluation results. Fig. 5 shows some results in the evaluation. Fig. 5(a) is the curve of the traffic flow. It differs from the M curve in a normal day and has an additional peak period from 20:00 to 21:00, which is caused by the two matches, i.e., football and badminton, ending around 20:00. Fig. 5(c) is the curve of the average speed in this day. It also has an additional valley from 20:00 to 21:00. Fig. 5(b) and (d) are the 4-h rooms of Fig. 5(a) and (c), respectively, and they show the traffic parameters clearer.

Based on these data, quantitative analysis can be conducted for the two evacuation plans. For example, the mean values of the average

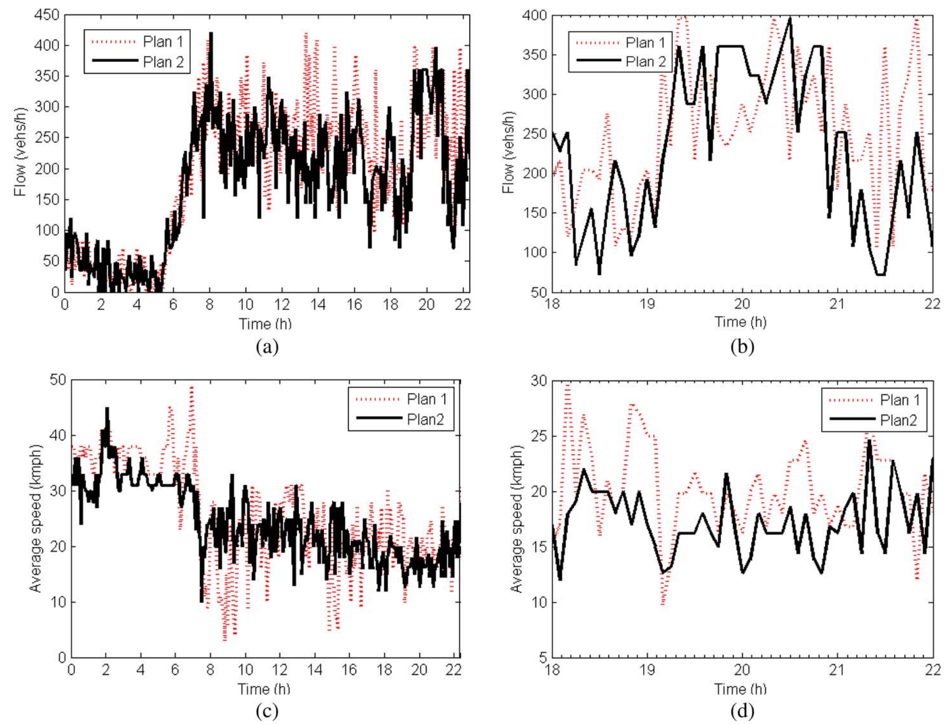

Fig. 5. Computational experiment results of evacuation plans 1 and 2 for November 19, 2010. (a) One-day traffic flow data. (b) Four-hour room of (a). (c) One-day average speed data. (d) Four-hour room of (c).

TABLE II
ANNOV OF THE DATA IN FIG. 5(c)

Source	SS	df	MS	F	Prob>F
Columns	401.7	1	401.668	5.92	0.0153
Error	38963.9	574	67.881		
Total	39365.6	575			

TABLE III
ANNOV OF THE DATA IN FIG. 5(d)

Source	SS	df	MS	F	Prob>F
Columns	210.18	1	201.184	16.79	8.71248e-05
Error	1201.5	96	12.516		
Total	1411.69	97			

speed in Fig. 5(c) are 28.5 and 26.38, and the analysis of variance (ANNOV) is shown in Table II. The result shows that we cannot reject the hypothesis $H_0 : \mathrm{AV}_{\mathrm{plan1}} = \mathrm{AV}_{\mathrm{plan2}}$ at the confidence level of 0.99, i.e., the differences of the two plans are not statistically significant. Next, we narrow the comparison period to only between 18:00 to 22:00. The mean values of the average speed in this period are 20.16 and 17.23. Table III shows the ANNOV of this period. The result shows that we can reject the hypothesis $H_0 : \mathrm{AV}_{\mathrm{plan1}} = \mathrm{AV}_{\mathrm{plan2}}$ at the confidence level of 0.9999, i.e., the differences of the two plans are statistically significant.

V. CONCLUSION

The public transportation system plays an important role for evacuation in large-scale activities. However, there are still many challenges in the modeling and analysis of the system, as it is both too huge and too complex to be modeled using traditional methods.

The ACP approach has been adopted by this paper to build PPTSs. The framework of the PPTS is designed, and how to establish the services on intelligent traffic clouds is also discussed. A case study is carried out for the Guangzhou 2010 Asian Games, and the effectiveness of the PPTS is verified through the evaluation of two transportation evacuation plans for the Asian Games.

This paper has presented the initial stage of our plan to improve the public transportation management in Guangzhou. Currently, one specific PPTS that covers the whole city is under construction. In addition to the 2010 Asian Games, the employed PPTS will be used to handle critical situations such as the peak traffic flows in the Spring Festival Seasons, the transportation in the China Import and Export Commodities Fair, etc.

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