Integrated Intelligent Control and Management for Urban Traffic Systems

Fei-Yue Wang

Abstract — **This paper is a brief summary of the recent development of integrated intelligent control and management system for urban traffic systems in China at the Key Laboratory for Complex Systems and Intelligence Sciences of the Chinese Academy of Sciences. The key technologies employed in this development include hierarchical intelligent control systems, agent-based control (ABC) and artificial transportation systems (ATS) for network-enabled traffic operational systems. The integrated system covers surface street intersection signal control, freeway/road entrance/exit ramp metering, and integrated traffic network control, guidance, and management.**

Index Terms — **Urban traffic control systems; intelligent transportation systems; hierarchical intelligent control systems; agent-based control; artificial transportation systems.**

I. INTRODUCTION

DEPLOYMENT of Intelligent Transportation Systems (ITS) has been identified as one of the twelve national key areas of research and development in China's Tenth Five-Year Plan from Year 2000 to 2005. As indicated by Figure 1, the highway system in China has experienced a significant growth over the last decade, from virtually none to a network of over 25 thousand kilometers crossing the nation, and becomes the second longest one in the world behind the United States. Meanwhile, Chinese automobile industry expands explosively over the last few years, and will reach 20% of the worldwide automobile market by 2020 based on a conservative annual increase rate of 5% (currently over 15%) and an annual output of 10 million vehicles [1]. The sharply increased number of passenger vehicles, the driving force behind the automotive industry and with an annual growth rate close to 30% currently, has made urban traffic congestion an even more urgent problem for the existing road network. Therefore, it is quite natural for China to shift its focus from building road infrastructure to developing transportation intelligence for high performance and better service, as already experienced by many other industrial countries [2].

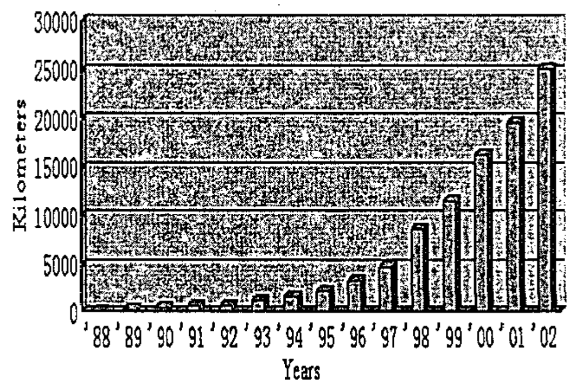

Fig. 1: Recent Development of Highway Systems in China.

II. TRAFFIC NETWORKS IN BEIJING

In 2001, China announced that 10 large cities in the nation had been selected as "Model Cities" for ITS field-testing and evaluation, and Beijing, the capital city of China was the top on the list. Beijing, also the host city of Olympics 2008, has an area of 16,807 squares of kilometers, a population of over 13 million permanent residents and 5 million temporary and seasonal workers from outsides. The city can be divided roughly into two parts: the suburban rural counties and the central city districts. Figure 2 (a) shows the road network for the entire city and Figure 2(b) presents the road structure for the central city districts, which is quite unique in the world. As one can see from Figure 2(b), the road network for the central districts expands from six arterial loops, where the first loop is a straight segment in the center stretching from the East to West, while the fifth and sixth loops connecting the districts with the counties are still under development. The traffic congestion and air pollution have been the two major problems facing Beijing over decades, and also the two central concerns for the successful execution of Olympics

Manuscript received March 1, 2003.

This work is funded in part by the Key Project Funds from Knowledge Innovation Program, CAS, Oversea Outstanding Scientist Program from CAS and the State Planning and Development Council, Outstanding Young Scientist Research Fund from the National Science Foundation of China, and the ATLAS Center of the University of Arizona. The support and contribution from research staffs and students at the Key Laboratory of Complex Systems and Intelligence Science, Institute of Automation, Beijing Traffic Administrate Bureau, and Research Institute of Highway Systems are greatly appreciated.

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2008. Recently, Beijing government has made tremendous efforts in solving those problems and ITS technology is expected to play an important role in their solutions.

A joint effort has been made since 1999 to develop ITS techniques for Beijing traffic control and management by the Chinese Academy of Sciences (CAS), Beijing Traffic Administrative Bureau, National Center of ITS Engineering and Technology, China, and the ATLAS and PARCS Centers at the University of Arizona, USA. The project is funded mainly by the Knowledge Innovation Program from CAS, the National Science Foundation of China, and the CASIC Corporation. Figure 3 describes the functional architecture and the control center of Beijing Traffic Command and

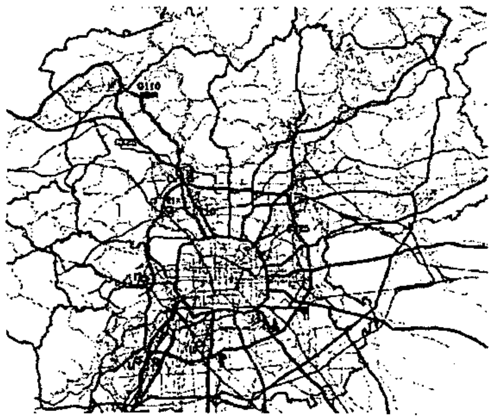

Fig. 2 (a): Road Network of Beijing City

Fig. 2 (b): Road Network of Central City Districts.

Dispatching System (courtesy of the Beijing Traffic Administrative Bureau), which consists of the Central Traffic Control and Management Center with eight regional centers, and seven subsystems for traffic monitoring, regulation, guidance, GPS/GIS, emergence handling, data collection, and traffic signal control, respectively. At this stage, the system is employing over 200 TV monitoring devices, 400 automated electronic traffic police systems, 250 GPS-equipped traffic patrolling vehicles, 130 fixed/mobile variable message systems for traffic and parking, the 122 emergence reporting system, 1400 inductance loops and 200 microwave/video traffic data collecting units, and 240 intersection controllers. One major problem toward a coordinated and intelligent traffic signal control in Beijing is how to incorporate the new system with the existing SCOOT traffic controllers, which had been installed over 100 intersections in 1980s but considered a failure. The current system will be expanded greatly over the next two years.

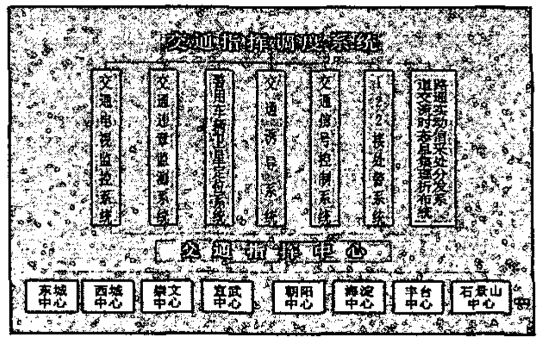

Fig. 3 (a): The Functional Architecture of the Beijing Traffic Command and Dispatching System.

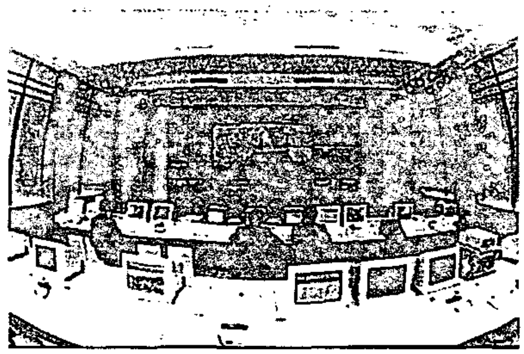

Fig. 3(b): The Control Center of the Beijing Traffic Command and Dispatching System.

III. KEY TECHNIQUES

Traffic networks are typical complex systems involving engineering, human, and society, and their control and management solutions demand an interdisciplinary approach through the combination of many innovative scientific and engineering methods. In this project, three major techniques have been employed for ITS. First, the hierarchical intelligent control systems are used to solve the complexity issues for traffic networks through decomposition [3]. Second, the agent-based control (ABC) method and the principle of "local simple, remote complex" are used to provide a low cost but high performance and intelligence method for networked traffic controllers of street intersections and freeway entrances/exits [4, 5]. And finally, the concept of artificial transportation systems (ATS) has been introduced to offer an in-the-loop emulation with real-time traffic information to support certain traffic decision-makings. This approach was developed based the well-developed simulation technology in transportation systems and the newly emerged research area of artificial societies [6]. In

ATS, complicated traffic behaviors and situations will "grow" and emerge from the interaction of simple traffic regulation, vehicle and human behaviors, so they can be used for traffic control, guidance and management.

IV. System Architectures and Platforms

The focus of ITS R&D at the CAS is to create an integrated and intelligent traffic control and management system based on real-time traffic data and communication, online GPS/GIS information, and strategies for global coordination and optimization. Its objective is to develop and implement prototype and deployable ITS modules, platforms, and integration techniques that could result in significant reduction in traffic congestion, travel time, and air pollution. Considering the specific structure of road networks in Beijing and its existing facilities, the development effort has been divided into three parts, consisting of building intelligent hierarchical control and management systems for 1) networked surface street intersections, 2) coordinated surface road/arterial loop interaction and loop ramp metering, and 3) integrated traffic guidance, monitoring and dispatching. Figures 4, 5, and 6 present the architectures for the three systems. In addition to conventional system analysis and decision-making techniques, major new methods used in developing those systems include intelligent control, agent-based control and programming, game theory, data mining, data fusion, fuzzy logic, neural networks, and genetic algorithms in computational intelligence. Artificial transportation systems and its in-the-loop network-based implementation with real-time traffic data have been used to support the traffic decision-making process. The web-based software platform and its integrated development environment, called GreenPass-iTOP, have been developed for both on-line and off-line operations for network communication, system configurations, date collection, monitoring and inspection, simulation and forecasting, information analysis and broadcasting, as well as traffic control, guidance and dispatching, as indicated by Figures 7-9. A more detailed description of this system can be found in [7, 8, 9].

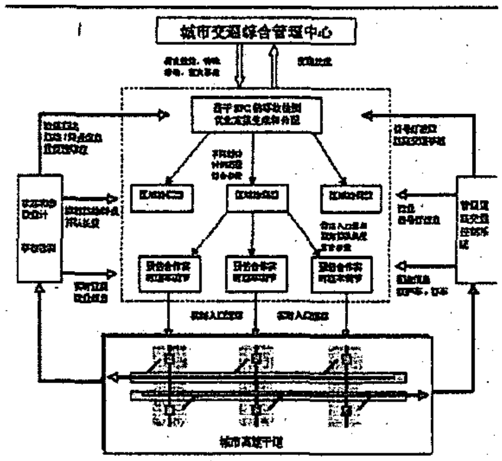

Fig. 5: System Architecture for Coordinated Road/Loop Interaction and Ramp Metering.

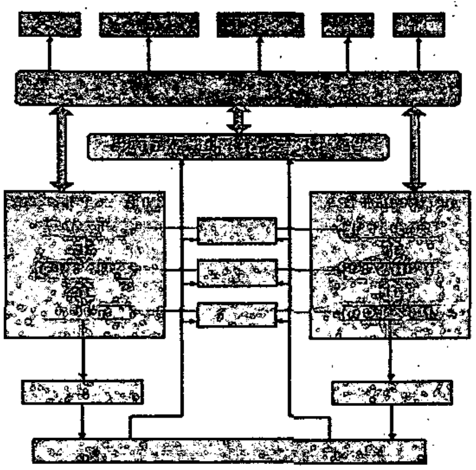

Fig. 6: System Architecture for Integrated Traffic Guidance, Monitoring and Dispatching.

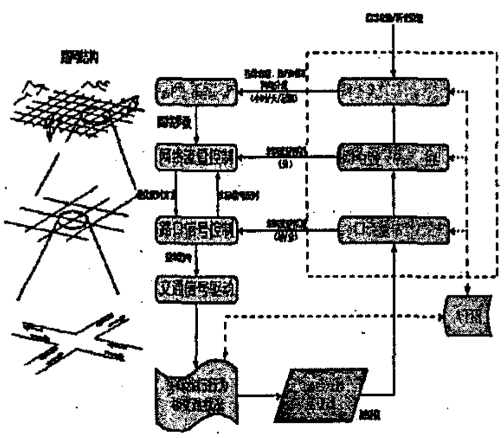

Fig. 4: System Architecture for Networked Surface Street Intersections.

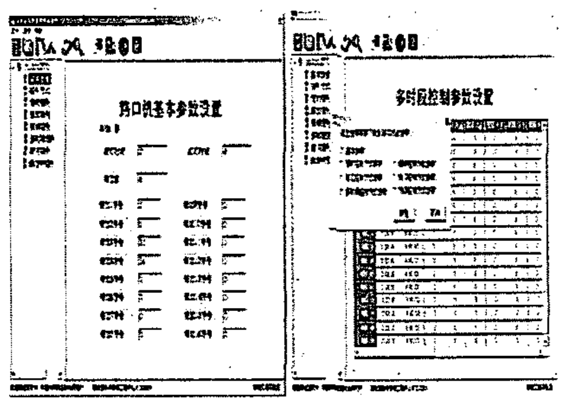

Fig. 7(a): System Configuration Interface

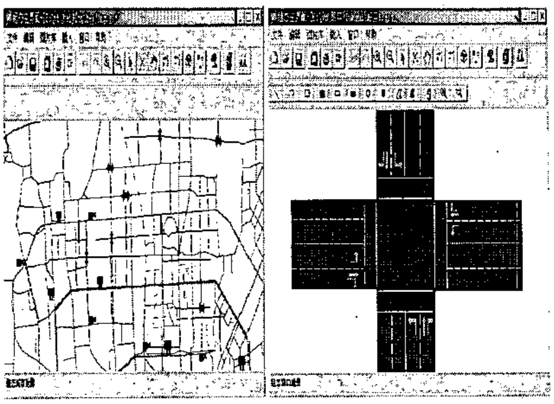

Fig. 7(b): System Configuration Interface

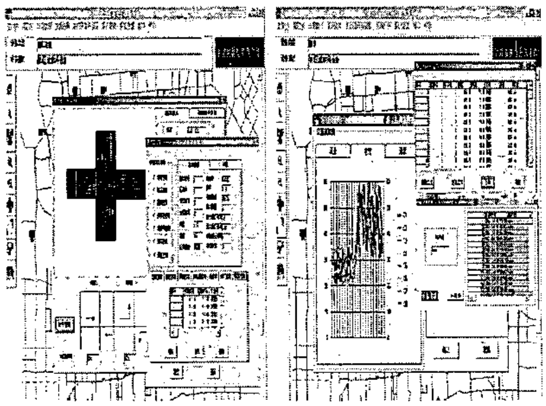

Fig. 8: System Monitoring and Control Interface

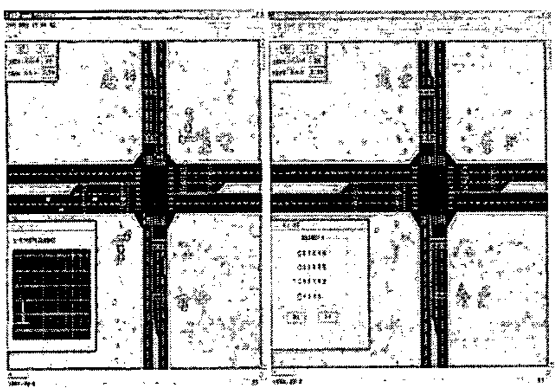

Fig. 9: System Simulation Interface

V. Laboratory and Field Testing and Evaluation

In 1999, an ITS Laboratory had been established within the Intelligent Control and Systems Engineering Center of the Institute of Automation at the Chinese Academy of Sciences for the purpose of developing, testing, and evaluating traffic control and management systems. Figure 10 shows some of lab facilities and Figure 11 is the hardware architecture and an earlier version of the intersection traffic controller developed in the ITS Lab based on the 2070 specification and an embedded application specific operating system (ASOS). An expanded and comprehensive testing laboratory will be established soon in the National Field Testing Facility for ITS in Tong County, Beijing. Since 2002, deployments have been made for actual traffic controls in cities outside Beijing and several site evaluations have being conducted currently.

Fig. 10: ITS Laboratory at the Chinese Academy of Sciences

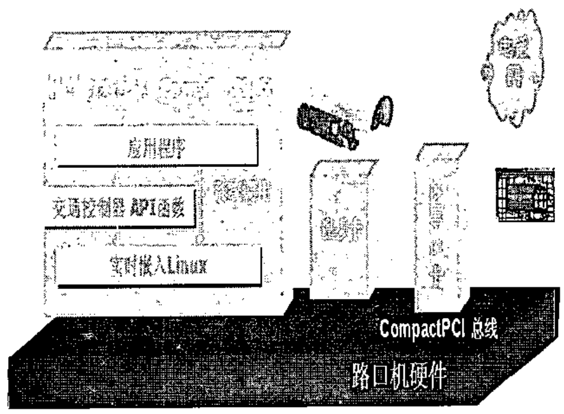

Fig. 11(a): Hardware Architecture of CASIC Intersection Traffic Signal Controller

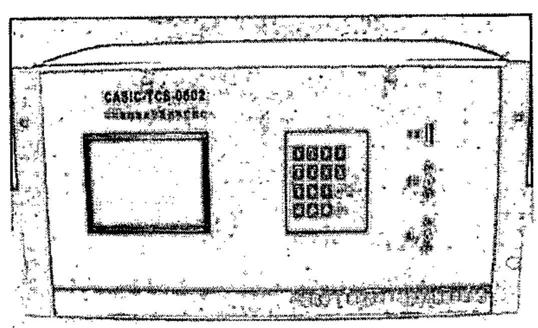

Fig. 11(b): A Prototype of CASIC Intersection Traffic Signal Controller

VI. Conclusion

The control and management of the traffic system in Beijing offer a gold opportunity to validate and deploy ITS concepts and techniques for both China and the World. Although tremendous progresses have been made over the last three years, the road to a full functional and integrated intelligent traffic operation system in Beijing is still a long and difficult one. With only five years left, we hope that the effort of this project and many others would make Olympics 2008 not only a grand festival of world athletes but also an exciting demonstration of effective ITS technology.

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Fei-Yue Wang received his Ph.D. in Electrical, Computer and Systems Engineering from the Rensselaer Polytechnic Institute, Troy, New York in 1990. He jointed the University of Arizona in 1990 and became a Full Professor of Systems and Industrial Engineering in 1999 and currently is the Director of the Sino-US Joint R&D Center for Intelligent Control Systems, the Director of the Key Laboratory of Complex Systems and Intelligence Science at the Chinese Academy of Sciences. In 1999, he found the Intelligent Control and Systems Engineering Center at the Institute of Automation, Chinese Academy of Sciences, Beijing, China, under the support of the Outstanding Oversea Chinese Talents Program. His current research interests include modeling, analysis, and control mechanism of complex systems; agent-based control systems; intelligent control systems; real-time embedded systems, application specific operating systems (ASOS); applications in intelligent transportation systems, intelligent vehicles and telematics, web caching and service caching, smart appliances and home systems, and network-based automation systems. He has published more than 200 book, book chapters, and papers in those areas since 1984 and received more than $20M from NSF, DOE, DOT, NNSF, CAS, Caterpillar, IBM, HP, AT&T, GM, BHP, RVSI, ABB and Kelon. He received Caterpillar Research Invention Award with Dr. P.J.A. Lever in 1996 and the National Outstanding Young Scientist Research Award from the National Natural Science Foundation of China in 2001. He was the Editor-in-Chief of the International Journal of Intelligent Control and Systems from 1995 to 2000, and currently is the Editor-in-Charge of Series in Intelligent Control and Intelligent Automation and an Associate Editor of the IEEE Transactions on Systems, Man, and Cybernetics (SMC), IEEE Transactions on Robotics and Automation, IEEE Transactions on Intelligent Transportation Systems (ITS), and several other international journals. He is an AdCom member of IEEE SMC and IEEE Intelligent Transportation Systems Council (ITSC), and the secretary of IEEE ITSC. He was the Program Chair of the 1998 IEEE Int'l Symposium on Intelligent Control, the 2001 IEEE Int'l Conference on Systems, Man, and Cybernetics, the General Chair of the 2003 IEEE Int'l Conference on Intelligent Transportation Systems, and will be Co-Program Chair of the 2004 IEEE Int'l Symposium on Intelligent Vehicles and the General Chair for the same conference in 2005. He was the Vice President of the American Zhu Kezhen Education Foundation, the Chinese Association of Science and Technology-USA.