Transportation 5.0 in CPSS: Towards ACP-based Society-Centered Intelligent Transportation

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***Abstract*—In this position paper, we aim to provide our argumentation on why the society-centered intelligent transportation system (ITS), or Transportation 5.0, is the inevitable course for future ITS development. We also provide our statement on the solutions to society-centered ITS: the cyber-physical-social system (CPSS) architecture and parallel system methodology. Cornerstone technologies, such as knowledge automation, ontology, society perception and prescription, software defined integrated communication and computing, parallel intelligent techniques, and Parallel Blockchain, are also addressed in the position statement. Our best practices in Transportation 5.0 are also demonstrated to support our position. In the conclusive remarks, we provide our visions and expectations in future society-centered intelligent transportation system.**

***Index Terms*—Intelligent transportation systems, cyber-physical-social-systems, parallel system, ACP, knowledge automation, parallel intelligence, parallel learning, parallel dynamic programming, blockchain, Transportation 5.0.**

I. Transportation 5.0: The Society-Centered ITS

By the traditional definition in [1], Intelligent Transportation Systems (ITS) are "a set of solutions based on the combination of telecommunications and computer technologies designed and developed to improve the management, maintenance, monitoring, control and safety of transport". Therefore, ITS include multi-faceted of system services, such as automatic traffic management systems, transportation information services, traveller information systems, fleet management and location systems, electronic payment systems, cooperative vehicular systems, etc. The technologies that support ITS are mainly categorized into V2X Communications, Sensing and Surveillance, Computing and Data Analytics, and Application Related System Engineering. However, we believe a complete ITS is a socio-technical system, which consists of dual perspectives of both technology and society, while the aforementioned current ITS definition is mainly from the perspective of technology.

From the angle of **social operation and development**, transportation systems constantly supply movements of people and goods, supporting modern social activities. In other words, underdeveloped transportation will be the barrier of social development and can even cause social recession. At the same time, transportation system development makes substantial influence on the regional economic layout and urban morphology. For example, Studies have shown that cities with clustered high population density tend to relate closely with bicycles and buses as the mode of transportation; cities with radial satellite city structures are usually related to transportation means of bicycles, buses and rail transit; cities with a morphology of low density residential suburb and high population density in central urban, are closed related to a comprehensive transportation system with private cars, public transportation, and rail transit.

In our society, **personal and public transportation demand** sharply contradicts the demand from social welfare, that is, the convenience of private traffic comes at the expense of the high consumption of road resources. The earlier goal of transportation planning in some U.S. cities targeted at ensuring effective private transportation, however, decades of development suggested evident failure of this effort, instead, causing serious environmental pollution and traffic jam.

Social activities related travel, which can be generally understood as travel for social activities [2], is growing with increasing percentage of the whole social travel. In developed countries such as the U.S. and Germany, social activities are the reported purpose for a large number of trips, ranging from 26.5% to 39.5% [3]. In some developing countries, such increase is even more evident, e.g., the ratio in Beijing reached 19.07% in 2011 with a 26.8% increase from 2010 [4], [5].

Human factors are also critical to ITS [6]. Human factors play vital roles in all the technology areas that ITS dramatically change, including vehicle control design, traveller information management, fleet operation planning, and traffic management console. Further, early and gradual acceptance of ITS by the public and society directly affect the design of ITS morphology. For example, human factors need to be emphasized as early as in the phase of ITS test programs, as they are important information sources for the public to accept new ITS paradigm.

From social morphology, to social transportation demand, social activities, and human factors, ITS are tangled with human societies at every level, and thus, it is our belief that the society plays an equal or even more important role as transportation technologies, in the eventual development and evolution of ITS. However, currently, either in the European ITS Framework Architecture [1] or the National ITS Architecture in the USA, the society and transportation related social factors are used as background and context in most cases, passively providing sensing and surveillance data and passively reacting to the ITS. On the contrary, in our opinion, **the society should**

an active entity in ITS, proactively interacting and participating in the ITS processes of sensing, communicating, computing, control and management, which is proposed as Transportation 5.0. Indeed, Transportation 5.0 is a great leap from previous technology-centered ITS, and obviously it is a system with tremendous complexity. Investigation on such socio-technical systems was deemed infeasible, until the recent advent of Intelligent Technology Era (the New IT Era), i.e., cyberspace should enable new methods and systems to solve complex and challenging problems in the real world that have found no effective solutions so far. The advancements in Artificial Intelligent (AI) technology, large-scale computing, software defined communication networks enable the study, development, deployment and operation of Transforation 5.0, which is stated in the following sections.

II. Statement: Architecture and Methodology

A. Cyber-Physical-Social-Systems

The phrase cyber-physical systems (CPS) aims to "describe the tight conjoining of and coordination between computational (or cyber) and physical resources, that is, systems that feature a tight integration between computation, communication, and control in their operation and interactions with the task environment in which they are deployed" [7]. On top of CPS, Cyber-Physical-Social-Systems (CPSS) is defined as CPS tightly conjoined, coordinated, and integrated with human and social characteristics. It is our strong belief that social and human dimension should be deeply incorporated into CPS as the new space with an equivalent status of cyber- and physical-spaces, rather than only as background and context.

This change is companied with a philosophical implication that aligns CPSS with Karl Poppers theory of reality, which states that our universe consists of three interacting worlds: the physical (World One), mental (World Two), and artificial (World Three) [7]. In our view, CPSS will be an enabling infrastructure coordinating and integrating Poppers three interacting worlds, and elevating artificial intelligence to complex intelligence. CPSS promises a conceptual infrastructure for advancing complex systems with philosophical implication, directly benefiting our society. Spaces become intelligent systems when they are able to observe their own situation, construct a model of themselves, communicate with their inhabitants, and act based on their own decisions. After mapping spaces to intelligent systems, the next question lies in how they mutually interplay for generating intelligence in complex systems, which is introduced in the next section.

B. Parallel System Methodology and ACP Approach

The CPSS infrastructure promises a scenario where a real system and its artificial counterparts are operating in parallel and interacting through cyber-space. Such cyberspace-enabled parallelism opens a range of new complex system operation mechanisms, such as intelligent driving, integrated traffic management, vehicular safety, energy efficiency, reduced pollution, and maintenance services.

The characteristics of parallel system theory include data-driven modeling, artificial systems, and analytics based on computational experiments. The core concept of the parallel system theory is to establish one or multiple virtual artificial systems in the cyberspace in corresponding with the real physical system under investigation. The virtual systems are with various purposes such as scheduling, testing, control, management, etc. Through investigating and shaping the virtual systems, and interacting with the real physical system, the goal of management and control of the real physical system is achieved [8]. It is worthy of noting that, recently, parallel learning [9] and parallel dynamical programming [10] are derived from the parallel system theory.

The creation of the virtual artificial systems utilizes a complex system analytic approach, i.e., the ACP approach [11]. The ACP approach consists of "artificial systems" (A), "computational experiments" (C) and "parallel execution" (P) [12], which is described as following.

- **Artificial Systems (A):** Utilizing data from the real physical world and the virtual artificial world, through mining the data, discovering the embedded "intrinsic meaning", meanwhile together with data-driving and semantic modeling, one can construct artificial systems to pair with the real physical system by Merton's law;
- **Computational Experiments (C):** It is difficult to use a single analytic mathematical model to describe all the possible complex system dynamic conditions, instead, the dynamics needs to be modelled by computational experiments. Computational experiments utilizing "social computing approaches integrate important social factors in system operation such as consumers, social activities, weather, policy & regulations, etc. In such way, a deeply integrated socio-technical system model is created.
- **Parallel Execution (P):** The virtual artificial system and real system are paired to form a parallel system, the interactions of the virtual and real systems generate the feedback mechanism for controlling and managing the physical processes in the real system.

III. Statement: Cornerstone Technologies

Following parallel system methodology and utilizing ACP approach, we list the following cornerstone technologies for transportation CPSS, i.e., Transportation 5.0. Although a multitude of technologies can be considered as cornerstones for CPSS, in this position paper, we mainly address the cornerstone technologies that directly enable CPSS and parallel systems.

A. Knowledge Automation based Parallel System Service Middleware

In an intelligent system, a service oriented architectural framework is essential for organizing all the services to form a whole integrated system, with the final goal being to achieve decision-making and knowledge automation for these services. This high level design of the intelligent system aims at solving the following problems: *1)* How to integrate all the services into one united intelligent system while keeping each of them working independently; *2)* How to encapsulate related data sources and intelligent techniques into each service, and extract required knowledge and information. We name this architectural framework as "Service Middleware", with such middleware, a social application is decomposed into layered encapsulated services with clear boundaries, data source requirements, communication and computing source requirements, and AI techniques to be employed.

Decision-making and knowledge automation (DKA) is a scientific management approach. It connects all the related services in an operating organization together, conducts evaluation, boundary definition, data source definition and knowledge encapsulation for each service [13]. DKA defines the interactive mechanism among different system services, as well as the data and intelligent approaches for each particular service, therefore, realizes automation in decision-making and knowledge generation. The details of DKA include:

- Value Estimation: how to define a measurable value for the service related knowledge;
- Process Modeling: how to model the entire decision-making process utilizing only a group of the decision points in this process, and how to automate the decision-making process using decision services, which have been encapsulated with necessary service knowledge. These services will be published by service rule management systems (SRMS), and be called by service process management systems (SPMS).
- Knowledge Encapsulation: Encapsulation of service rules, algorithms and predictive analysis tools, framework establishment for automatic decision-making; determining the four critical components supporting the decision-making, i.e., SPMS, SRMS, predictive analysis models, and database.
- Decision Requirement Analysis (DRA): Decomposition of the decision-making process into network structures, which can be described by decision requirement diagrams (DRD). DRD illustrates the relationships among decision-making, knowledge domain and data domain.
- Development of knowledge automation projects: Demonstration of all the critical points in organizing a knowledge automation project utilizing DRD structure, which are scope classification, service estimation, project planning, knowledge discovery, design, development, configuration and testing. To modularize the decision-making process using DRA can create highly efficient knowledge production lines.
- Intelligent techniques for discrete and hybrid system modeling, such as Petri Net and its variations, are common approaches to design service structures.

B. Ontology based on Enhanced RFID

Ontology, in the context of computer science, is an academic discipline for modeling and describing the world that consists of "entities, ideas, and events, along with their properties and relations, according to a system of categories". Common components of ontology include Individuals, Classes, Attributes, Relations, Function terms, Complex structures, Restrictions, Rules, Axioms, and Events. Ontology is the foundation of semantically modeling a complex virtual system in the cyberspace. However, the issue arises that how any object in the real physical world can be given an identity and mapped into the virtual world. We believe the current booming enhanced RFID technology is an important player in taking such responsibility. An enhanced RFID system is able to label any object (or person) with minimum costs, and store information such as its attributes and relations. In the real physical world, an RFID tag can be easily read and written, also can be tracked. Recent development of RFID can identify the identities and behavior of objects all together, providing rich ontology information about the object under investigation. Thus, in our opinion, modern RFID and similar semantic technologies plays the part of bridging objects in real physical world and their counterparts in the virtual world, and provides accurate real-time information on identity, attributes, relations. This lays the foundation of ontological modeling and investigation of parallel systems.

C. Parallel Society Perception and Prescription

Sensors convert energy in the physical world to digital data (**energy-to-data**), such as motion, pressure, lights, fluid, temperature, electromagnetic field, and other emerging sensing modalities. Incorporating the new dimension of the social space, in CPSS, the concept of sensing is extended to **social perception**, which embraces sensing in physical space and perception of the society and people. We name the process of social perception as **minds-to-data**, which provides understanding of social and human factors, and reflects the situation of both physical and social spaces. Possible resources of social perception include social management data sources, commercial activity data sources, social network, online commercial information, social department data sources, personal natural language sources, unstructured text data, etc. Obviously, social perception needs to effectively choose data sources and accurately extract useful information from social Big Data.

Actuators convert digital data to energy in the physical world (**data-to-energy**) for applying control and management measures on physical devices, such as motion actuators, electric actuators, thermal actuators, mechanical actuators, and other application-specific and emerging actuator modalities. In CPSS, the concept of actuating is extended to **social prescription**, including both actuating in physical space and prescription of the society and people. One characteristic of social prescription is **data-to-minds**, which provides control and management measures to physical devices and also society and people. Possible resources of social prescription include governmental management measures, commercial influence, social network influence, social department recommendation, personal decision-making recommendation, etc. Social prescription opens a new dimension of effectively control and manage both physical and mental spaces.

Both social perception and social prescription need to solve complex issues, i.e., accurately choose data sources and extract useful information from social Big Data, and effectively and precisely actuate and affect a large number of devices and minds. Leveraging the parallel system methodology and ACP approach, through studying the corresponding virtual system by computational experiments are AI techniques, we believe Society Perception and Prescription can be successfully achieved.

D. Parallel Software Defined Integrated Communication and Computing

Cloud computing provides shared computing and storage resources on demand, in either privately owned, or third-party data centers. The data centers may be located anywhere globally, which is not a concern of the users. The model of could computing together with its backbone communication support is adequate for the current social needs in data exchange and analysis. However, the recent development of CPSS and Internet of Things (IoT) brought new demand in data volume, network work latency, real-time performance, and efficiency [14]. Thus, we expect that the computing paradigm in the near future will shift to integrated multi-layer mist-fog-cloud computing and software defined networks.

Enabled by the recent technological advancement, software-defined networking (SDN) [15] moves the decision making process from distributed network devices to a logically centralized controller. As a result, SDN is implemented as software running on commodity servers. The development of SDN is expected to highly improve the capability and flexibility of the network, and play an important role in the next generation networks. Fog Computing refers to an architecture for computing, storage, control, and communication network with the following features. 1) A substantial amount of storage, communication and computing are carried out at or near the end users, rather than core or backbone networks. 2) The services provided by fog storage, communication and computing are highly related to the provided service temporally and spatially. Small-scale fog computing facilities, which are even closer to the end users such as users' portable smart phones and tablets, are also named Mist Computing. Mist computing, fog computing and cloud computing constitute a multi-layered computing infrastructure, undertaking computing tasks with different requirements in complexity, latency and scales of data. Both SDN and fog computing are with very strong social characteristics, reaching out to every detail of our society, therefore they are natural candidates of CPSS cornerstone technologies.

Both SDN and multi-layered computing infrastructure are socio-technical complex systems, and are in need of mechanisms for their joint designing, implementation, planning, scheduling and operation, for the communication and computing purposes derived from their social services. Again, utilizing the parallel system methodology and ACP approach, we believe a new framework of integrative communication-computing will become realistic, a recent study was presented in [15] on initial investigation on parallel control and management of SDN.

E. Parallel Intelligent Techniques

Integrating parallel system methodology and modern artificial intelligent techniques, parallel intelligent techniques begin to surface and show powerful capability in solving problems in complex systems. In this section, the following parallel intelligent techniques are presented as illustrative examples of such practices.

a) Parallel Learning and Deep Networks:: Deep Learning (DL) is a branch of machine learning [16]. Currently, the major frameworks of DL include deep neural networks, convolutional neural networks, deep belief networks, recurrent neural networks, etc. The DL approaches are being applied in many research fields such as computer vision, audio recognition, natural language processing, and biological informatics, and achieved tremendous success. Utilizing the synergy of DL and parallel system theory, a new framework of machine learning theory, parallel learning, is proposed in [9], which incorporates and inherits many elements from various existing machine learning theories. Special designs can be incorporated into the parallel learning framework to address important issues in the machine learning research field, e.g., effective data retrieval from big data using software defined artificial systems, combination of predictive learning and ensemble learning, application of Merton's law to prescriptive learning, etc.

b) Parallel Dynamic Programming: Integrating adaptive dynamic programming theory and parallel system theory, a new framework of dynamic programming, the Parallel Dynamic Programming (PDP), is proposed in [10], [17]. PDP is able to incorporate various modern intelligent techniques into its framework, such as aforementioned parallel learning, deep learning, deep network, reinforcement learning, rule-based expert system, etc. The PDP greatly enhances the capability and applicability of dynamic programming to complex social systems and engineering systems, by introducing the ACP approach.

F. Parallel Blockchain

Blockchain, widely known as one of the disruptive technologies emerged in recent years, is experiencing rapid development and has the full potential of revolutionizing the increasingly centralized intelligent transportation systems (ITS) in applications [18]. Blockchain can be utilized to establish a secured, trusted and decentralized autonomous ITS ecosystem, creating better usage of the legacy ITS infrastructure and resources, especially effective for crowdsourcing technology. [18] conducts a preliminary study on Blockchain-based ITS (B^2ITS), and outline an ITS-oriented, seven-layer conceptual model for blockchain, and on this basis address the key research issues in B^2ITS. A case study was provided on blockchain-based realtime ride-sharing services. In our viewpoint, B^2ITS represents the future trend of ITS research and practice, and this paper is aimed at stimulating further effort and providing helpful guidance and reference for future research works.

IV. Best Practices in Transportation 5.0

A. Parallel Transportation Management System in Qingdao

Although Transportation 5.0 has been proposed for a short time, such concept has been already applied for the Parallel Transportation Management System in Qingdao (PtMS-

Qingdao), Shandong Province, China [19]–[21]. The budget of PtMS-Qingdao was over RMB 720 million (about $120 million). The project was financially supported by the Qingdao government, conducted by Qingdao Academy of Intelligent Industries, Qingdao Public Traffic Administration, HiSense, State Key Laboratory for Management and Control of Complex Systems (SKL-MCSS), Tsinghua University, and National University of Defense Technology, and is the biggest ITS project in China so far. Our research team has embedded mobile app data into the system and utilized PtMS to connect with people and vehicles. The artificial transportation system uses social signals from mobile phones, microblogs, Wechat, and other social media to represent traffic condition and knowledge, computational experiments for simulation and predication, and parallel execution for traffic control and management in a closed-loop approach. All data sources are cross-validated with $1,020$ physical sensor sites, 424 signal-control intersections, $1,500$ detectors, 350 traffic signs, 20 VMS, 50 speed-limit road, and 50 flyovers embedded citywide. According to the third party evaluation and verification published at The Qingdao Morning Post, comparing with the traffic situation before the implementation of PtMS, the average travel time on major roads has been reduced by 20%; the number of vehicle stops reduced by 45%; congestion miles reduced by 25%; and overall travel efficiency improved 43.39%. At 2015 IEEE 18th International Conference on Intelligent Transportation Systems (ITSC 2015), PtMS Qingdao Project (Phase I) has received “IEEE ITS Outstanding Application Award.

B. *Five Transportations in One*

Five Transportations in One is our on-going practice, where urban traffic, public transport, parking management, regional logistics, and social transportation will be integrated and relevant data would be shared for scientific research, technology development, and better services [19]–[21]. Such practice is in the context that Qingdao has decided to make Intelligent Industries one of its main engines for future economic and social development. A cross-department agency will be created to implement Transportation 5.0, in which, in addition to Five Transportations in One, a smart automated harbor system will be built and a special road about 50 km long to the new international airport for autonomous vehicles will be constructed. This will be a bold and difficult task. Big data and intelligent technology for cyber-social-physical systems, especially ACP based parallel intelligent technology, will play a central role for its success. We expect Transportation 5.0 will lead to a new type of Transportation Catallactics, a self-organizing transport market for regulated coordination and voluntary cooperation, in which parallel systems serve as effective platforms and mechanisms for discovering and distributing information and knowledge for transportation activities.

C. *Intelligence Testing for Autonomous Vehicles*

This practice studies how to test the intelligence of an autonomous vehicle [22]. A new semantic diagram definition of driving intelligence is defined which explains the relationship between testing scenarios, tasks, and vehicle functions. We show that the testing scenario/tasks generation process and the functions evaluation process can be viewed as two transverses (with opposite directions) in the proposed semantic diagram. Utilizing existing parallel traffic systems, which proved to be able to compare the real behaviors observed in practice and the simulated behaviors generated in virtual space, field and simulation tests for autonomous vehicles are developed, and the new testing theory and methods are approved to be used to guide the Intelligent Vehicle Future Challenge that will be held in China in 2016 and 2017. We believe this set of new testing methods will help improve the developing of autonomous vehicles in the future.

D. *Evaluating Evacuation Plans for Large-Scale Activities*

In this practice, the parallel system and ACP approaches are adopted to build parallel public transportation systems (PPTSs) [23]. 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 practice presented the initial stage of our plan to improve the public transportation management in Guangzhou, and currently, one PPTS that covers the whole city is under construction. In addition to the 2010 Asian Games, the developed PPTS is 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.

E. *Urban Intelligent Parking System*

Parking system is one of the most important component of ITS, and its performance has a great effect on the entire transportation system [24]. The parallel parking system is proposed including the construction scheme for parallel parking system, detailed parallel resource management and control system, and the parallel parking guidance and information system. The parallel parking system could effectively optimize the parking system operations via the interactions between actual and artificial parking systems. By computational experiments and analysis of the artificial parking system, a control strategy to parking problems can be continuously updated and tracked on a real-time basis; meanwhile, the collected operating status of the actual parking system can also be used to optimize the model of the artificial parking system. Therefore, the parallel parking system could solve the current parking problems more efficiently, and it plays an important role to alleviate the pressure of urban parking.

F. *Traffic Flow Prediction Using Traffic Big Data*

In this practice, we propose a deep learning approach with a stacked autoencoders (SAE) model for traffic flow prediction. The proposed method can successfully discover the latent traffic flow feature representation, such as the nonlinear spatial and temporal correlations from the traffic data [25]. The training and testing data are collected from the Caltrans Performance Measurement System (PeMS) database. The traffic data are collected every 30 s from over $15,000$ individual detectors, which are deployed statewide in freeway systems across California. Experiments demonstrate that the proposed method for traffic flow prediction has superior performance.

V. Conclusions and Our Vision

For conclusions, we emphasize again our position, that is, we foresee a paradigm shift from technology-centered ITS to society-centered ITS (namely Transportation 5.0), and it is our belief that the solution for society-centered ITS lies in CPSS architecture and parallel system methodology. With CPSS and parallel systems as its foundation, cornerstone technologies in knowledge automation, ontology, social perception, social prescription, integrated communication and computing, intelligent techniques, and recently emerging blockchain, will proliferate to solve issues in and support such socio-technical complex system. Our past and ongoing practices in Transportation 5.0 also provide strong confirmation of our position and related statements. We believe, in the near future, with further development in the architecture, methodology, and technologies in CPSS, ITS will make a great leap to realize its society-centered morphology, and eventually enter the era of social computational transportation.

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