An Introduction to Parallel Control and Management for High-Speed Railway Systems

Bin Ning, *Member, IEEE*, Tao Tang, Hairong Dong, Ding Wen, *Senior Member, IEEE*, Derong Liu, *Fellow, IEEE*, Shigen Gao, and Jing Wang

***Abstract*—This paper introduces a framework of parallel control and management for high-speed railway systems (HRSs). First, based on multiagent modeling, an artificial HRS that is consistent with realistic operations of the actual HRS is constructed. Then, different kinds of computational experiments are performed on the artificial HRS, followed by analysis and synthesis with a case. Finally, through an interactive and parallel operation between the actual and artificial HRSs, a set of practical control and management strategies can be achieved for the actual HRS. With the primary objective of ensuring reliability and safety of HRSs, this study could enhance the quality of services and the integrated transportability with other existing modes of transportation systems to provide appropriate recommendations and strategies for forming an overall effective comprehensive transportation system.**

***Index Terms*—Artificial system, computational experiment, and parallel execution (ACP) method, high-speed railway system (HRS), parallel control, parallel management.**

I. Introduction

SINCE the first railway constructed in Stockton and Darlington in Great Britain in 1825, over the past 185 years, railways have rapidly developed not only in U.K. but in many other countries such as Japan, France, Germany, Italy, and China as well [1]–[7]. A great deal of effort has been devoted to the research and development of increasing train speeds and improving train operation safety [8]–[12]. As a means of safe and reliable, fast and comfortable, and high loading with low energy consumption, high-speed trains have become the future trend of railway transportation worldwide. In particular, this has been very rapidly developed in China since the beginning of the twenty-first century. After a decade of effort in building a large number of high-speed railways while upgrading some existing regular ones, China has now taking the lead in the world with its 7055 km of high-speed railways in service today, including passenger-dedicated commercial lines, intercity lines, and passenger–freight mixed lines of 200-km/h high-speed trains. An example in point is the "Harmony" high-speed train CRH380BL of peak speed 487.3 km/h tested through the Beijing-Shanghai line on January 9, 2011, making a new world record of commercial trains in operation.

According to the prediction of the Association of the European Rail Industry (UNIFE) [13], the high-speed train industry will be steadily growing at a 2%–2.5% average annual growth rate before 2016 worldwide. In many cases, railways can substitute and even replace part of the air and highway transportation business, creating huge opportunities for its own future development. Further increase of the high train speeds not only promote faster circulation of human capital, logistics, finance, and information flows but also help the emergence and establishment of space–time closer city clusters.

The high-speed railway system (HRS) is a complex system of interdisciplinary nature, acquiring comprehensive knowledge of almost all kinds of engineering and even economics, social science, natural resources, and climate studies alike. Today's railways include passenger-dedicated and intercity lines and, more commonly, passenger–freight mixed lines serving for both high- and low-speed trains. Railway management systems typically have locomotive and vehicles public work sections, traffic control and electricity distribution departments, and transportation organization and scheduling units, which altogether complicate the management of the railway system, particularly by their different and nonunified measurements and policies. In fact, not only the entire system but also its subsystems are very complex (see Fig. 1), in which all operations are complicated, and the system structure is intrinsically vulnerable to human ignorance in operations and management, as well as random disturbances from local and small damages and accidents.

The operation of high-speed railway transportation is affected by many factors and issues, such as the determination of holidays and people's vacation schedules. Moreover, statistics show that most emergencies of high-speed trains were due to the disorderly and irregular behaviors of passengers and pedestrians, as well as because of mismanagement of some operators and authorities. Take the HRS traffic control as an example. Usually, all the routine works in railway stations and bureaus are carried out by human operators, but due to human errors and emotional behaviors, there exist many high

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B. Ning, T. Tang, H. Dong, S. Gao, and J. Wang are with the State Key Laboratory of Rail Traffic Control and Safety, Beijing Jiaotong University, Beijing 100044, China (e-mail: bning@bjtu.edu.cn; ttang@bjtu.edu.cn; hrdong@bjtu.edu.cn; gaoshigen@bjtu.edu.cn; 09120267@bjtu.edu.cn).

D. Wen is with the Research Center on Computational Experiments and Parallel Systems, National University of Defense Technology, Changsha 410073, China (e-mail: wending2010@gmail.com).

D. Liu is with the Key Laboratory of Complex Systems and Intelligent Science, Institute of Automation, Chinese Academy of Sciences, Beijing 100090, China (e-mail: derong.liu@ia.ac.cn).

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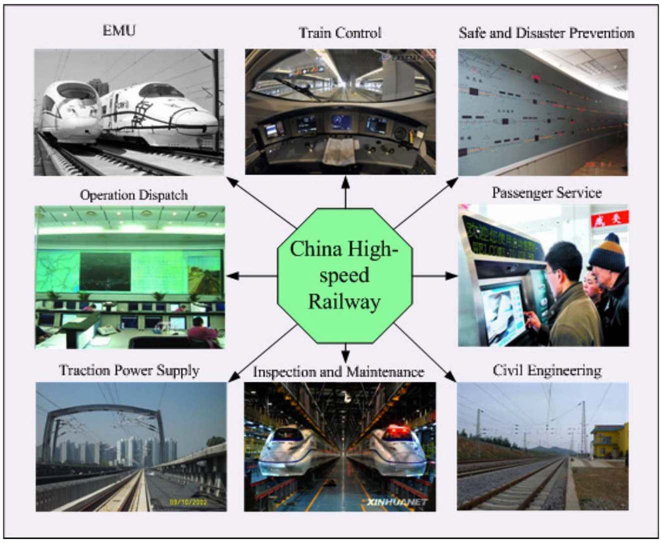

Fig. 1. China HRSs.

uncertainties. On December 17, 2000, a Japanese high-speed train had an unexpected brake failure during movement.

Although the train driver reported the incident to the control center immediately, the commander failed to alert the other train driver coming from the opposite direction, leading to a collision that left 1 dead and 27 injured. In September 2008, a train driver in South California failed to communicate with the control center, causing a train collision that left 23 dead and more than 130 injured. Such incidents clearly show that human factors must be taken into consideration in HRS control and management.

In case of emergency, it is natural to estimate and predict, beforehand, the potential causes, incident scenarios, and possible consequences. However, emergencies cannot be repeated by real-life experiments, and virtual simulations become a necessary alternative. This can provide realistic evaluation and analysis of HRSs in operation safety assessment, yielding useful guidelines and suggestions for better emergency handling and rescue management. It is thus very important to have a complete set of proved-effective regulations for HRS management and control to develop and maintain highly safe and low-cost high-speed train services.

Since the rapid development of computer and communication technologies, railway simulation software has seen more and more applications in railway construction planning, design, and management. VISION is a computer simulator developed by Britain Rail Research Division, AEA Technology Rail, which can be used to effectively analyze the duration of trains and capacity of lines in real time. LOGSIM, on the other hand, is another computer simulator developed in the United States, which is useful for train scheduling and traffic control. Moreover, OpenTrack, which was developed by the Swedish Royal Institute of Technology, can optimize train scheduling, and RailSys, which is a microsimulation system designed by the German University Hannover and the Deutsche Bahn Management Consulting Firm, can be sued for different-scale railway networks analysis, design, and optimization [14]–[16]. In addition, RAILSIM, which is a network simulator that is popular in North America, can accurately simulate the movement of any car on any railway system, and the Japanese simulator UTRAS is a general-purpose software that can be used to compute the train movement, estimate the effects of train modeling on commercial profits, recover delays, analyze the effects of different formats of signaling, and evaluate multicar train capability and performance, etc. RAILS, which was developed by the Canadian National Railway and the Corporate Strategies companies, can be used for comparing the theoretical capability and real capability of railway systems. There is also a computer simulation program that integrates Data Envelopment Analysis and Analytical Hierarchy Process, and some other multi-body simulations software, such as MEDYNA, NUCARS, SIMPACK, and ADAMS/rail [17]. It should be pointed out, however, that most of the existing computer simulators are developed based on train motion dynamics, railway network models, and the complexity of signaling systems but not on the management and control of train operations.

The study of complexity has gained significant progress in recent years [18]–[20], particularly with many breakthroughs after the late 1990s, impacting the evolution and development of computer simulation systems. Today, the decisions and scheduling of human travels by means of train transportation are much better understood, and a theory of activity-based human travel behaviors is reaching its maturity with many initial applications. Recently, advanced countries have further explored research and development in applications of activity-based traveling mode [21]. According to the most updated statistics, 40% of large-scale metropolitan planning organizations in the United States and 20% of medium-sized city planning organizations have used or about to use activity-based traffic models. Moreover, artificial life and artificial society studies also applied this theory, which have shown to be successful to some extent [22], [23]. Typical examples include the "sugarscape" model of Epstein and Axtel about growing artificial life [24], the spatial epidemic model EpiSims developed by Los Alamos Laboratory [25], and the artificial stoke market model of Santa Fe Institute [26]. These models demonstrate the feasibility of a bottom-up approach to establishing comprehensive social systems models. Meanwhile, the rapid developments of computer software technologies and network-computing infrastructures and methodologies have made large-scale social systems modeling and computation possible.

In 2004, Wang [27], [28] proposed a new concept of "TransWorld" of parallel systems, computational experiments, and artificial transportation. By first experimenting on an actual system via an artificial system, and then combining them, one is able to evaluate and modify a real plan completely, accurately, and timely and, moreover, can iteratively modify and optimize a management and control system in operation. This new methodology has been applied to transportation systems, power grids, Asian Olympics, and ethylene production [29]–[33].

Due to the rapid development of system informatics, computer networking, and artificial intelligence, as well as a huge-scale complex system involving economics, social, ecological, cultural, and human societies, in addition to external factors and random disturbances, it has become impossible to describe, analyze, and predict the HRS by using conventional models.

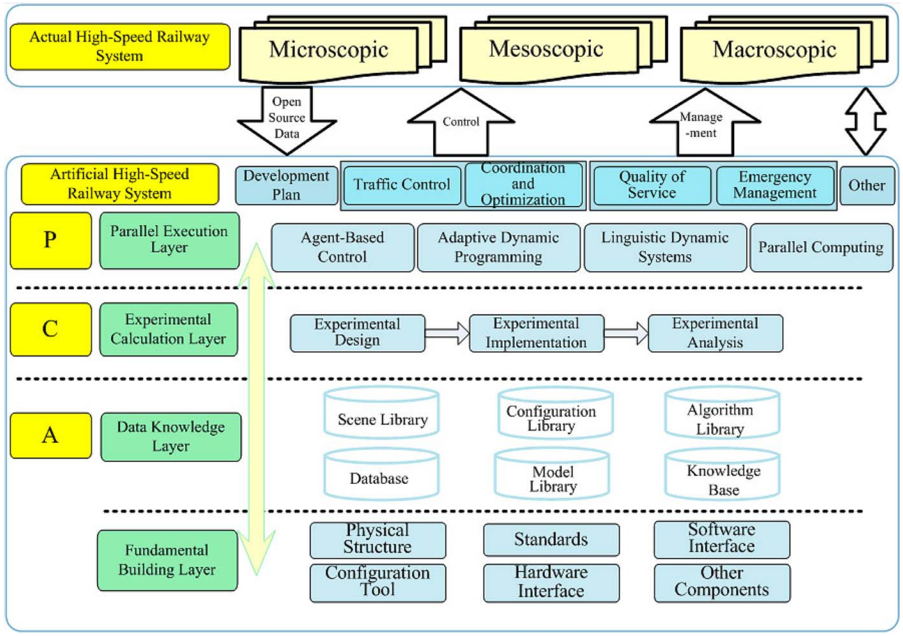

Fig. 2. Basic flowchart.

Traditional mathematical models attempt to control high-speed trains via discrete, static, and auxiliary formulations, and most simulation software did not take into account the integrated operation and management of HRSs and, therefore, cannot completely evaluate and effectively manage the system, letting alone the consideration of safety reliability, optimization, and intended objectives. Moreover, experimenting on the actual HRS is extremely expensive and even impossible. To resolve all such technological bottlenecks and challenges and avoid current and potential safety threats, it is necessary to resort to investigating complex system control to figure out a set of working plans and strategies. This paper combines the artificial system concept with the integrated operation and management of HRSs to establish a novel system of high-speed train parallel control and management, aiming at improving the integrated operation and management level of the current HRS. This is not only for the need for integrated traffic demands but also for lowering energy consumption, improving quality of services, and optimizing transportation systems design and management.

This paper is organized as follows: Section II introduces the high-speed railway parallel control and management system. Section III presents a detailed description of the agent-based artificial HRS model. Section IV analyzes the structure of a computational experimental platform, whereas Section V demonstrates both the parallel execution mode and the evaluation system of the parallel execution.

II. Basic Concepts of the High-Speed Railway Parallel Control and Management System

The high-speed railway parallel control and management system is an integrated system equipped with an HRS with related social factors and some "equivalent" artificial HRSs, including A (artificial systems), C (computational experiments) and P (parallel execution), as shown in Fig. 2.

The basic principles of the high-speed railway parallel control and management system are given as follows: 1) based on the framework of multiple agents, to establish an artificial system such that it is "equivalent" to the actual system, aiming at understanding the evolutional patterns of various factors within the systems; 2) to perform computational experiments or "tests" on the artificial system to simulate specific train operation and movement, as well as scheduling and management, to completely, accurately, and timely evaluate and adjust the whole systems; and 3) with the experience from the aforementioned learning and understanding, parallel executions are conducted by combining the artificial railway system and the actual system. Under normal circumstances, it can optimize the daily operation and reduce potential risk. Under abnormal circumstances, it can find a way to back up the system and resume its normal operations to reduce the lost. Furthermore, it can accomplish an overall analysis of operation control, safety and reliability, and management of the actual HRS.

Comparing with the traditional automatic system, which takes physical objects such as mechanics, pressure, and temperature into consideration, an artificial system, computational experiment, and parallel execution (ACP)-based parallel control system for HRSs will consider all the related factors, including anthropic, environmental, social, and economic. Once built, the novel control and management system will outperform the existing control system, as supported by our existing simulations.

III. Artificial High-Speed Railway System Model Based on Multiple Agents

Through the analysis of the actual HRS, an artificial HRS model can be built up, and its credibility can be verified based on the framework of multiple agents. The actual HRS does not use accuracy as the only yardstick, but it is considered as an alternative of the actual complex system. If the HRS

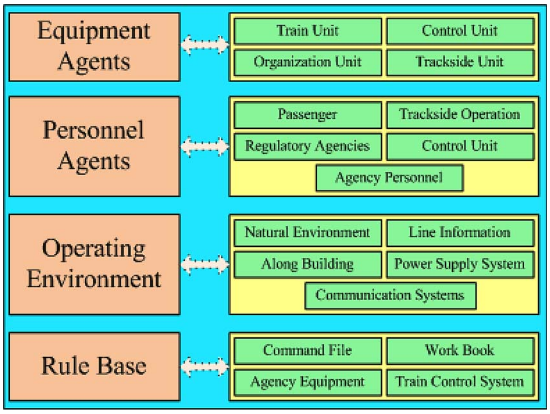

Fig. 3. Artificial HRS model.

is running under the environments of debris flows or other natural disasters, then such incidents are unpredictable, and the consequent harm and influences cannot be precisely described beforehand. Thus, an operational scheme used for a fixed scenario with constant road slopes, traffic lines, and train models cannot satisfy all train–road conditions and, similarly, cannot fit to the future phase of development. Therefore, scene- and data-based artificial HRSs should be constructed to respond to all kinds of possible scenarios.

Currently, there are many methods for modeling and simulating transportation systems, such as agent-based modeling and programming techniques, Petri nets and their variations, complex networks and linguistic dynamical systems, cellular automata and their generalizations, fuzzy logic, neural networks, genetic programming, and computational intelligence, including natural computing [34]–[44]. According to agent autonomy, sociality, learning, responsiveness, proactive, mobility, etc., this paper proposes an artificial HRS corresponding to the actual system for parallel control and management.

A. Components of the Model

The proposed artificial HRS mainly consists of four parts, namely, equipment agents, personnel agents, an operating environment, and a rule base. The basic structure is shown in Fig. 3.

1) *Equipment agents:* train units, trackside equipment units, monitoring units, railway train operation depots, locomotive terminals, etc.:
   a) train units: train and onboard equipment, where the onboard equipment includes Vital Computer, Balise Transmission Module, odometer and velocity measurement modules, and Radio Transmission Module;
   b) line side units: signals, switches, track circuits, balises, etc.;
   c) monitoring units: Radio Block Center, Computer-Based Interlocking, Train Control Center, the dispatching system, microcomputer monitoring, etc., where the dispatching system is divided into three levels, namely, the dispatching system of the Ministry of Railways, the dispatching and directing center of the Railway Bureau, and the dispatching offices in various stations;
   d) institution units: stations, railway train operation depots, locomotive terminals, vehicle depots, communication and signaling depots, track districts, passenger traffic sections, building maintenance districts, maintenance bases, etc. For every agent, the system assigns some attributes such as vehicle number and length, axle loads, grouping, tasks, tractive performance, braking distance, and so on. For the track agent, the system assigns name, direction, distance, track level and type, maximum grade, radius of curvature, track spacing, effective length of receiving departure track, etc.
2) *Personnel agents*: In the working process of the actual HRS control and management, every person who contributes to the systems will be considered as an agent.
   a) on-train personnel: drivers, mechanics, conductors, crew, passengers, etc.;
   b) sidetrack personnel: track construction, maintenance personnel, signaling equipment maintenance personnel, etc.;
   c) monitoring personnel: technical engineers, yardmasters dispatchers, track personnel, brakemen, operational duty personnel, etc.;
   d) institution personnel: train pickers, fare collectors, passenger and freight service personnel, passenger station staff, bus service segment and depot maintenance personnel, and other staff. For each agent, the system appropriately assigns corresponding actions, reactions, and mental, physical, and other attributes, which reflect the basic characteristics of that agent, such as intelligent thinking ability and independent task-taking ability, as well as decision making according to the changing environment. For example, the main corresponding attributes of the train drivers, mechanics, and conductors are their genders, ages, job titles, skills, etc., which are needed to be precisely described, along with their attitudes, personality, etc., which are needed to be vaguely described.
3) *Operating environment*: the actual physical environment or a mathematical computational environment. The operating environment of the artificial HRS model is constructed by infrastructure facilities and tracks (bridges, tunnels, stations, station yards, etc.), communication systems (high-speed fiber backbones, fiber-optic local area networks, and digital mobile communication systems, information access systems, and information channel systems), power supply systems, and the natural environment (ground, rains, snows, winds, and so on). The environment of the artificial HRS mimics the real environment of the actual system, from which the influences of the operating environment for the actual HRS can be also observed by customizing some environmental changes.
4) *Rule base*: agents, the environment, and the rules or methods that influence each other.
   a) operational factors of the train control systems: working modes, running rules, dispatching rules, driving rules, Temporary Speed Restriction (TSR) notices and interlocks, etc.;

b) performance and the operation manual for trains and tracks, and institutional management regulations for stations, railway trains operation depots, etc.;
c) management system: for railway staff, assessment criteria, operational regulations, etc.;
d) commands and order documents are activated by the Ministry of Railways, the national standards, and the occupation standards.

The whole model of the artificial HRS is constructed based on the aforementioned classification, and each agent follows its own standards and regulations in its own environment; thus, it not only is possible to reproduce the existing events but also can simulate and predict the real actions and behaviors in their future operations. The size of the system, the control method, the behavioral characteristics corresponding with the actual system altogether determine the effects of the parallel control. Therefore, after building all individual agents in the artificial HRS, it is necessary to verify the consistency between the artificial HRS and the actual HRS.

B. Credibility Verification

To ensure that the behaviors of the artificial HRS are consistent with that of the actual system as a whole, the verification of the credibility of the equivalent model is necessary. Credibility verification is analyzed for two aspects.

1) *Verifying the rationality of the structure*
   a) Device agents: Devices are the cores of the high-speed railway control systems; thus, the device agents need to maintain a completely consistent action with the actual devices, including the number of devices, functions, principles, etc.
   b) Personnel agents: Personnel agents are mainly composed of staff and passenger flows. Staff has the same pursuit of each individual, as they have a direct effect on all aspects of the high-speed railway operation control systems. Passenger flows have a lower impact on the high-speed railway operation control systems, which only ensure that the number and proportion of the passengers and other aspects can well approximate the actual one.
   c) Operating environment: The operating environment has the most direct effect on the operation of the HRS such as traveling staff, train speed, etc.; thus, the consistency between the model environment and the actual operational environment must be ensured.
   d) Rule base: Train dispatching rules and employee manuals provide direct commands and directive messages to the work and operation of the systems; thus, a consistent and complete rule base must be built.
2) *Verifying the behavioral consistency*

   Through verification of credibility, the system will ensure the behavior of the artificial HRS to approximate the behavior of the actual system. By correcting the errors and mismatches in the artificial system and by minimizing the differences between the artificial and actual systems, the system will amend some specific parameters of the corresponding individual or system agent to ensure the effectiveness, rationality, and reliability of the artificial HRS, thereby eventually achieving the equivalence between the artificial HRS and the actual HRS.

IV. Computational Experiments

The artificial HRS, once built, will be used as a platform for computational experiments. Through various experiments on the platform, many tests that cannot be performed on the actual system can be carried out, which provides a low-cost high-efficiency way for feasibility verification and evaluation for design and planning; thereafter, the actual high-speed railway can be safely controlled and effectively managed.

First, the research objectives will be analyzed and determined. Then, according to the involving units and personnel, design some tasks to be tested on the computational experimental platform and then store and analyze the simulation results and data. To that end, find out what are controllable and what are not, and based on which, rearrange personnel and facilities and adjust parameters and setting to improve any possible drawbacks and problems. By repeating the aforementioned procedure, one can finally reach an optimal or a near-optimal and practical scheme for the actual system.

Repeatedly executing, modifying, and reexecuting a scheme are put in force in the artificial HRS. The computational experimental platform can provide the actual system with reliable guidelines due to its merits of being low cost and highly efficient. These can significantly improve the management efficiency, train operation safety, quality of services, and on-time running scheduling. According to the different characteristics of various subsystems of the railway system, there are four computational experimental plans on train operation, central traffic control, services, and emergency dispatching, which are described in the list that follows.

1) *Train operation*
   a) Train operation control includes operation monitoring and control, overspeed protection, TSR, emergency braking (EB), and train location.
   b) Train safety monitoring includes automatic data collection, measurement and detection of real-time monitoring and control of various tracks and lines, signaling systems, communication systems, and off-track hazards, achieving alarm and early warning, information feedback analysis, and online tracking.
   c) Train organization and planning includes train scheduling, adjustment of train schedule charts, number checking of arrival and departure trains, and automatic generation of traffic timetables.
2) *Dispatch*
   a) According to the levels of administration, the whole dispatching system is divided into three levels, namely, the dispatching system of the Ministry of Railways, the dispatching and directing center of the Railway Bureau, and the dispatching offices in various stations.
   b) According to the job nature, the dispatching system is divided into vehicle depots, communication and

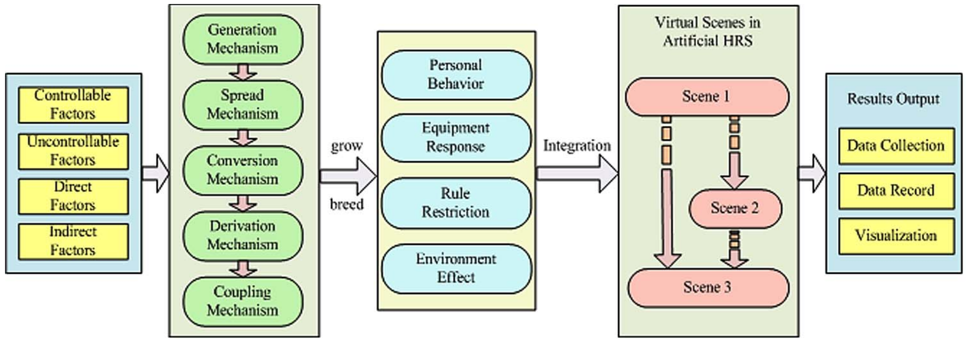

Fig. 4. Design of a computational experimental platform.

signaling depots, locomotive terminals, and maintenance bases.

3) *Services*

These include passenger service, freight transportation service, and railway staff management service, in which the passenger service is given the priority, including onboard service and scheduling consultancy, as well as evacuation from congestion, etc.

4) *Emergency handling*

a) human errors: their happening and correction;

b) natural disasters: due to weather hazards;

c) unavoidable problems: device failure and track aging, and their immediate handling.

A. Design of a Computational Experimental Platform

The most important component in computational experiments is the design of the platform, which is used to evaluate the effects of controllable, uncontrollable, direct, and indirect factors on the system output (see Fig. 4), such as the effects of human operational errors on train running, the effects of environmental changes on the entire system, and so on.

In the computational experimental process, the artificial HRS can be used as a repeatable simulation platform, where events constitute a scheme database for a large number of experiments with various conventional controllable and uncontrollable factors. All of the scheme, computational results, evaluation parameters, etc., will be recorded and filed, and the corresponding scheme database, the file database, and a database management system will be established to provide scheme resources, computational data, and experience of revision for future repeated experiments and parallel executions.

B. Experimental Data Processing

This is to collect data and perform data mining and fusion from the complex social phenomena of various artificial agents' behaviors that mimic the virtual "actual" systems. Based on the computational experimental data of the artificial HRS, the operational safety, transportation efficiency, service quality, and economic index will be analyzed as follows (see Fig. 5).

1) Operational Safety: Operational safety is the foundation of efficient operations of the integrated HRS. Since the train speeds are becoming higher and higher and the railway network becomes denser and denser, operational safety has become the major requirement of the HRS today, where the time interval of train traveling reflects the maximum capacity of passenger loading and affects the design criteria and complexity of the system directly. The computational experimental platform can be used to complete the tasks of estimating the train traveling time intervals and the train overloading results and then to evaluate their consequences.

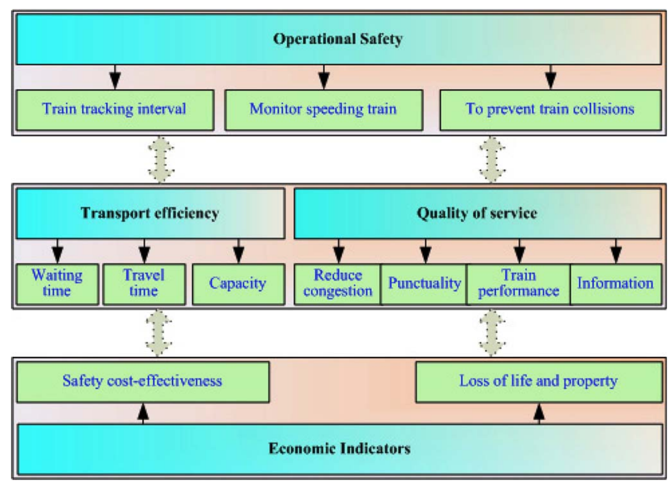

Fig. 5. Computational experimental data processing.

2) Transportation Efficiency: As human social activities become broader and more frequent, society financial activities also become more active; consequently, traveling becomes more important in terms of life quality improvement. As a result, people are expecting more convenient and faster railway services, demanding shorter waiting and travel time. The computational experimental platform can be used to simulate how to guarantee the passengers' waiting time, train traveling time, and transportation network capacity and how to make adjustments, if necessary.

3) Service Quality: In artificial system modeling, human factors and passenger service problems will be considered insufficient details to provide high-quality and efficient ways for services. Based on the computational experiments, quality of services can be assessed by means of reducing passenger-flow density, train on-time arrival rate, train riding comfort during start and stop, train schedule information, etc.

Fig. 6. Artificial system of the southern Beijing railway station.

4) Economic Index: All the planning and business solutions that are too expensive or impractical on an actual system can be simulated on the artificial computational experimental platform, which provides various computational results that are useful for economic evaluation, such as the cost–profit ratio, safety benefits, and property lost.

In computational experiments, all planning and business solutions, computational results, and evaluation parameters will be recorded and filed into the plan database, information database, and database management systems as data information resources for future repeated experiments and parallel execution.

C. Case Study

As aforementioned, the artificial HRS can be used as a platform for computational experiments. In this section, an artificial system for the southern Beijing railway station (see Fig. 6) is established.

Based on the artificial HRS, the following two aspects in the computational experiments are discussed: 1) passenger-flow analysis and 2) daily train operations. The objective is to guarantee a passenger average minimum transference time between urban train Line 4 and Intercity Train (the first intercity line with an operating speed above 300 km/h in China), namely, transferring all the passengers from urban train Line 4 with the least possible delays by rescheduling the departure time of the Intercity Train. The structures of passengers and train agents, as well as their logical relations, are shown in Fig. 7. To reduce the volume of waiting passengers in the station, we adjust the pullout interval of intercity high-speed trains dynamically, as shown in Figs. 8 and 9. The results show significant reduction in the waiting volume of passengers in the station through the computational experiments on the artificial HRS platform.

V. Parallel Execution Based on the Artificial High-Speed Railway System

Based on the understanding of the actual HRS evolution, which is gained from the simulations on the artificial computational experimental platform, one is ready to combine both the artificial and actual railway systems to form a high-speed railway control system. Since the actual HRS is very difficult to measure, predict, and analyze, and it is impossible to perform experiments on the actual system, utilizing the great potential of the artificial HRS platform is very important for low-cost and high-efficiency operation of the actual HRS, by improving its role and functioning from passive to proactive, static to dynamic, offline to online, following to leading, and so on.

A. Parallel Execution Mode

Repeating a large number of computational experiments on the artificial railway system platform and using sufficiently many plans with possible solutions from the databases, one can integrate the artificial platform and the actual railway system to execute real control and management in parallel. As shown in Fig. 10, there are two types of parallel execution.

1) Global execution

   Connect all modules between the artificial railway system platform and the actual high-speed system, input different proposals and plans, obtain corresponding outputs, and then feedback necessary changes and corrections after evaluation.

   If the artificial system platform has some time ahead, then one can predict the integrated performance and behavior of the actual system. For example, passenger flows rapidly increase during holidays and vacation times, which will create great pressure on various service systems of train stations and exceed their normal loading capabilities. In such cases, the tasks of setting up additional temporary ticket windows, new station gateways, and more efficient ticket-checking services will be handled by new solution plans developed on the artificial system platform.

2) Local execution

   Choose one or more units from the artificial HRS according to the need of the research plans and perform local communication to their real counterparts while other units are operating independently. Based on data obtained from the connected units and from the observed behaviors and results of the entire system, carry out adjustment and optimization accordingly to the evaluation system.

   Today, due to the rapid increase of high speeds in train movements, the existing requirements for safe operations and technical skills need to be further improved. Based on the integration of the artificial and actual systems, the technical workers and management personnel training will become much more cost effective.

B. Evaluation System

The safety, reliability, comfort, and economy of the high-speed parallel control and management system are all important for the integrated design of the HRS, including railway train operation depots, locomotive depots, rolling stock depots, communication and signaling sections, and signaling systems, providing their individual operational manual. Accordingly, the design, construction, testing, adjustment, interconnecting, and extraconnecting are all very important, implying the necessity

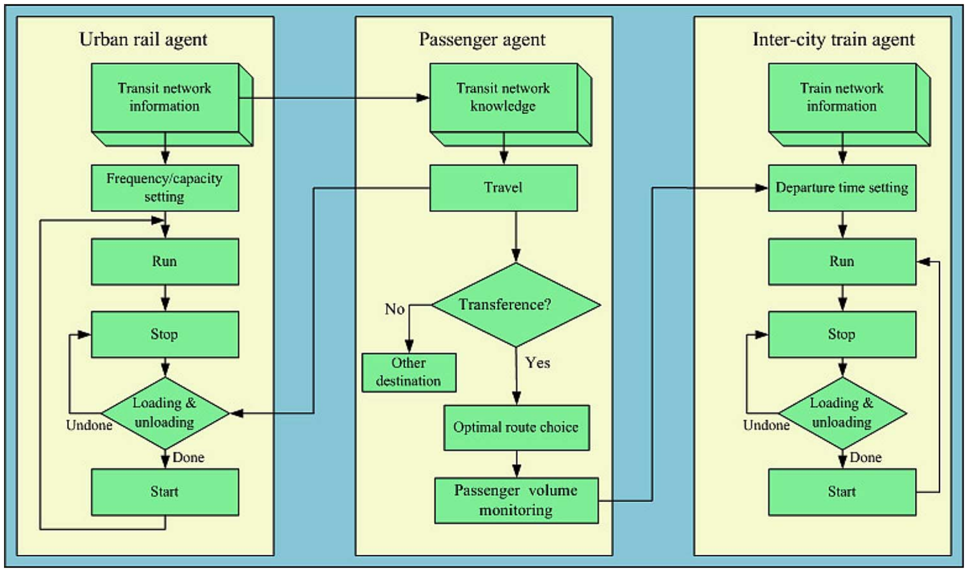

Fig. 7. Agent-based modeling diagram.

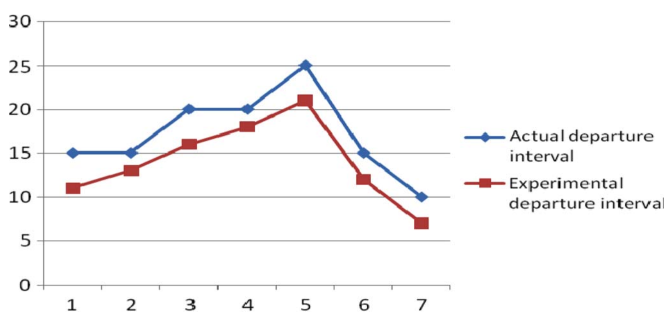

Fig. 8. Actual and experimental departure intervals.

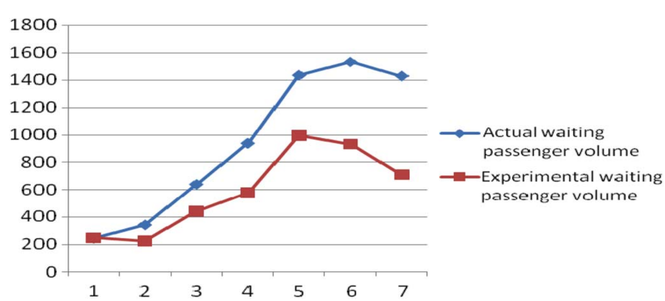

Fig. 9. Actual and experimental waiting passenger volumes.

and importance of the evaluation system of parallel execution from integration to management to operation.

1) *Global-level evaluation system*: from the perspective of economics, social effects, and persistent development.

   a) Economic evaluation contains two stages, namely, construction and operation.During the construction period, there are many uncertain factors in determining railway locations and stations; therefore, a comprehensive economic evaluation system can help have high efficiency in the implementation of planning. For example, in the stage of choosing track lines, it is required to have good estimation and evaluation of geological conditions, city economic status and future, freight transportation demands, residents' expectation of ticket prices, etc., which will provide necessary information for cost–benefit ratio evaluation and the impact of high-loading freight transportation on the logistics system, as well as the impact of dedicated train lines on social and financial activities.During the operation period, the main concerns are as follows: frequency and volume of train operations, train start and arrival scheduling, train-speed control, train parking time in stations, passenger occupation rates in different times, profit evaluation, etc.

   b) Social effects evaluation includes quality of passenger services, high efficiency of social freight transportation due to e-commerce, and loading release of highway, river, and air transportation, as well as their percentages and portions in the integrated transportation systems, which will benefit freight transportation and economic development, for example, in western China.

   c) Persistent development evaluation mainly includes low carbon consumption and energy efficiency, with low pollution.The improvement of railway transportation capability and loading capacity will significantly dilute the traffic of highway, river, and air transportation; lower the global energy consumption; and reduce air pollution due to carbon dioxide generation from gas burning. The HRS should be built based on the concepts of "eco-transportation" and "green transportation" system, toward a highly efficient and integrated energy-efficient HRS. In addition, personnel management, organization structural simplification, work-efficiency improvement, etc., are also key factors of persistent development evaluation.

2) *Management-level evaluation system*

A key issue in railway operation is safety in transportation. Basically speaking, a safety assurance system in railway transportation is a system with the backbone at "management" and the center at "human" and encompassed by "environment," which altogether guarantees a

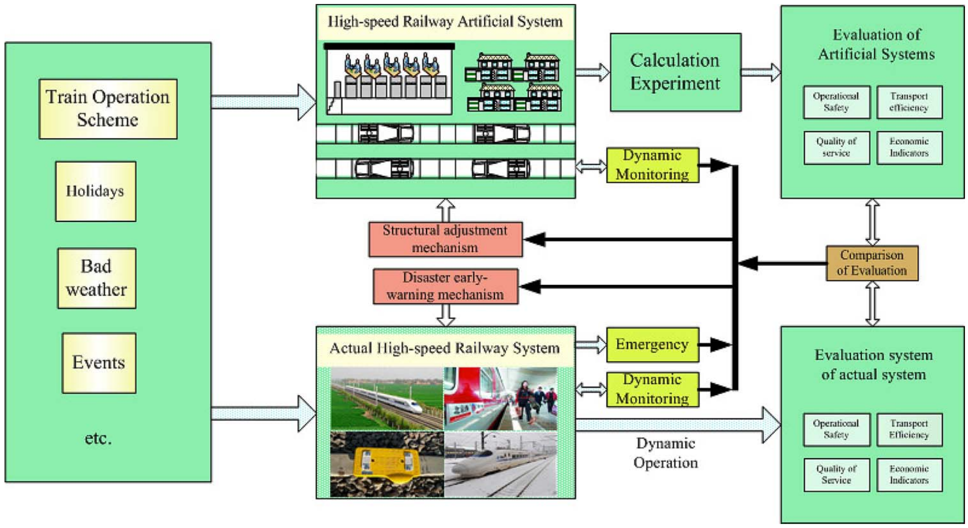

Fig. 10. Parallel execution.

"man–train–environment" system for safe railway transportation. Within this system, "management" penetrates into all branches and units, organizing them into an integrated entity, in which "human" is the subject and the object of "management": the higher the level, the more subjective the "human." The human factor plays a major role in accidents in railway operation nationwide; therefore, the management-level evaluation system is of most importance, which includes the following.

a) The central management system is a top-down hierarchical, cross-board, multiline, and real-time coordinative management system. A cross-board management system is necessary, such as using a train control system to control and manage station scheduling centers, Computer-Based Interlocking (CBI) control systems and safety inspection devices, assurance systems, etc., as well as an integrated scheduling system that can control and manage communication and signaling sections, locomotive depots, and railway train operation depots.

b) In the middle level of the railway management system, its mutual control and management are in equal positions, but they are in parallel, interconnective, intercommunicative, and cooperative operations. Examples include the cooperative and coordinative management among station scheduling centers, CBI control systems, safety inspection devices and assurance systems, communication and signaling sections, and railway train operation depots.

3) *Operation-level evaluation system*

The operation-level management system of the HRS can be divided into two parts.

1) Evaluation system for the subsystem composed of trains, including Automatic Train Operation, Automatic Train Protection, automatic emergency management of human errors due to mis-operations of train drivers, onboard communication devices, reliability of data transmission, energy saving, driver's technical skills, and correct operations of devices.

2) Evaluation system for sidetrack subsystems composed of rail quality and road quality, working mode of balises, signal formats and their efficiency, inspection equipment and devices liability, timely line maintenance, fixing of track mechanics, etc.

VI. Conclusion

As the rapid development of information technology and increase of society demands, the HRS has evolved to become increasingly complicated and complex, with higher connectivity and interactions with its various subsystems, exhibiting many interrelated features of dynamic, fast-speed, and real-time properties. Taking into account social, natural, engineering, and cultural aspects, and considering the dynamical evolution of the complex HRS, it is evident that establishing a global model for the integrated system is extremely difficult and that the current control system theory is hard to apply. Therefore, in this paper, we have proposed a new concept of HRS parallel control and management. The key issue is to establish an artificial HRS that is highly consistent with the existing actual HRS to resolve the limitation of the conventional centralized control and management system. It integrates all subsystems (personnel, control, scheduling, etc.) to model the actual system, taking into account the cooperation and coordination between the actual and artificial systems, as well as data processing and fusion. It carries out computational experiments and compares the results with the actual situations to predict the special and temporal future changes of the HRS, thereby suggesting plans and solutions to safe operations and efficient management of the actual HRS, which will lay a foundation for future development of an integrated comprehensive modern high-speed railway transportation system.

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Bin Ning (M'94) received the B.S. degrees from Northern Jiaotong University (now Beijing Jiaotong University), Beijing, China, in 1982, where he received both the M.S. and Ph.D. degrees afterwards.

He was a Visiting Scholar with Brunel University, London, U.K., from 1991 to 1992 and with the University of California, Berkeley, from 2002 to 2003. He is currently a Professor with the State Key Laboratory of Rail Traffic Control and Safety, Beijing Jiaotong University, as well as the President of Beijing Jiaotong University. He has directed many key national scientific projects in China. His scientific interests include intelligent transportation systems, communication-based train control, rail transport systems, system fault-tolerant design, fault diagnosis, system reliability, and safety studies.

Prof. Ning is a Fellow of the Institution of Railway Signal Engineers and IET, a Senior Member of the China Railway Society, and a member of the Western Returned Scholars Association. He is the Chair of the Technical Committee on Railroad Systems and Applications of the IEEE Intelligent Transportation Systems Society.

Tao Tang received the Ph.D. degree from the Chinese Academy of Sciences, Beijing, China, in 1991.

He is currently a Professor and the Director of the State Key Laboratory of Rail Traffic Control and Safety, Beijing Jiaotong University. He has participated in several major projects on high-speed trains funded by the Chinese government. He is one of the leading scientists with extensive experience in high-speed train control, safety, and energy saving.

Hairong Dong received the B.S. and M.S. degrees in automatic control and basic mathematics from Zhengzhou University, Zhengzhou, China, in 1996 and 1999, respectively, and the Ph.D. degree in general and fundamental mechanics from Peking University, Beijing, China, in 2002.

She is currently a Professor with the School of Electronic and Information Engineering, Beijing Jiaotong University. She was a Visiting Scholar with the University of Southampton, Southampton, U.K., in 2006; the University of Hong Kong, Pokfulam, Hong Kong, in 2008; the City University of Hong Kong, Kowloon, Hong Kong, in 2009; and the Hong Kong Polytechnic University, Kowloon, in 2010. In 2007, she served as a Project Level-3 Expert with the Department of Transportation for the Beijing Organizing Committee for the Olympic Games. Her research interests include stability and robustness of complex systems control theory, intelligent transportation systems, automatic train operation, and parallel control and management for high-speed railway systems.

Ding Wen (M'95–SM'99) is currently a Professor and a Senior Advisor of the Research Center for Computational Experiments and Parallel Systems with the National University of Defense Technology, Changsha, China. His main research interests include behavioral operation management, human resource management, management information systems, and intelligent systems. He has published extensively and received numerous awards for his work in the aforementioned areas.

Derong Liu (S'91–M'94–SM'96–F'05) received the B.S. degree in mechanical engineering from the East China Institute of Technology (now Nanjing University of Science and Technology), Nanjing, China, in 1982, the M.S. degree in electrical engineering from the Chinese Academy of Sciences (CAS), Beijing, China, in 1987, and the Ph.D. degree in electrical engineering from the University of Notre Dame, Notre Dame, IN, in 1994.

He was an Assistant Professor with the Department of Electrical and Computer Engineering, Stevens Institute of Technology, Hoboken, NJ, from 1995 to 1999. In 1999, he joined the University of Illinois at Chicago, where he became a Full Professor of electrical and computer engineering and of computer science in 2006. He was selected for the "100 Talents Program" by the CAS in 2008. His current research interests include intelligent control theory and applications, artificial neural networks, computational neuroscience, power systems, and automotive engine control.

Dr. Liu is a member of Eta Kappa Nu. He is the Editor-in-Chief of the IEEE TRANSACTIONS ON NEURAL NETWORKS.

Shigen Gao received the B.S. degree from Tianjin University of Technology, Tianjin, China, in 2009. He is currently working toward the Ph.D. degree with the School of Electronic and Information Engineering, Beijing Jiaotong University, Beijing, China.

His current research interests include intelligent transportation systems, automatic train operation, and parallel control and management for high-speed railway systems.

Jing Wang received the B.S. degree in 2009 from Beijing Jiaotong University, Beijing, China, where she is currently working toward the M.S. degree with the School of Electronic and Information Engineering.

Her current research interests include parallel control and management for high-speed railway systems and intelligent transportation systems.