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Parallel Intermodal Road-Rail Transportation System based on ACP Approach

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Abstract**—Intermodal road-rail transportation Systems (IRRTS) is a typical complex giant system which is difficult for traditional management approaches to form effective solutions with dynamic adaptability. In the physical world, simple equipment upgrading and transport optimization can't satisfy the demand of IRRTS for high efficiency and low cost. Thus, a framework of parallel IRRTS based on ACP approach including artificial IRRTS, computational experiments and parallel execution is proposed. The artificial IRRTS is the foundation of parallel IRRTS, which can be constructed based on multi-agent modeling. In this paper, the structure of the IRRTS is analyzed in detail, while eight types of agents are designed to model all of the entities in an IRRTS, and the artificial IRRTS is constructed considering the interactions among all types of agents. Therefore, the management and control for IRRTS in physical world can be tested and computed through the artificial one, and the systems' operation efficiency will be improved.**

Keywords—intermodal road-rail transportation; ACP approach; artificial system; parallel managemen and control.

I. INTRODUCTION

Intermodal road-rail transportation systems (IRRTS) has experienced a phenomenal growth over the past two decades [1], and has been widely used in Europe especially in European Union, such as Cargobeamer of Germany and LOHR of France. North America started later than Europe but its IRRTS developed better, with representative systems such as RoadRailer and RailMate. The domestic research on IRRTS is still in exploration with road haulage independent of rail freight. Nowdays, integrating the two modes and building the management & mechanism for interconnection of logistics information are very urgent, since China has a huge population and great potential market. In particular, the country is promoting supply-side reform considering the nowdays Internet and sharing economy, which makes it important to develop China's IRRTS.

Various physical, social and cultural factors and complicated technologies are involved in IRRTS, making the system difficult to be described by traditional mathematical models. In addition, as a result of the intra- and inter-regional relations, IRRTS works as a typical distributed system. Current IRRTS can realize interactions between the physical equipments and the information system to some extent, but still has some problems, such as opaque logistics information, poor transport synergy, information in distributed equipments can't be shared, and non-real-time interactions because of the management strategies. So the main problem is how to surmount limited physical resources and take full advantage of both the transport network data and various kinds of social media data to create a comprehensive and transparent logistics information environment, thus help to optimize transport scheduling, customize transport services and intelligent management and control for IRRTS, etc.

Parallel systems have been widely used to optimize the management and control for complex system [2]. It consists of using artificial systems to model the real system with a bottom -to-up method called agent-based modeling, computational experiments to compute and evaluate the possible logistics situations in the artificial systems, and parallel execution for applying the evaluted best strategy possible to solve problems encountered in the physical system, which is in short called the ACP approach. The physical system can be continuously optimized by strategies outputed by the artificial one, while the artificial systems use information feedbacked by the real situations in physical system[3-7]. The ACP methods has been tried in traffic, process industry, e-commerce and aerospace industry [8-11].

Based on the ACP approach, this paper proposes the parallel logistics systems for IRRTS. The rest of the paper is organized as follows. Section 2 reviewd the state-of-the-art in IRRTS research, and the current problems in the field. Section 3 introduced the framework of parallel logistics system. Section 4 gave the method of establishing artificial system by agent-based modeling, and Section 5 concluded our work.

II. Literature review

Foreign researches on IRRTS mainly focus on the following aspects: (1) operation mode [12-13]; (2) multi-actor chain management and control[14-15]; (3) transshipment[16-19]. Rodrigue [12] presents a method to handle intermodal terminals facility with scheduling time, goods distribution, transport time, energy and environment efficiency, to solve IRRTS bottlenecks in North America. Kordnejad [13] develops an Intermodal Transport Cost Model (ITCM) based on rail operations cost, road haulage cost and terminal handling cost, to evaluate the feasibility of IRRTS operation mode. Taylor and Jackson [14] examine the role and market power of each actor in the intermodal system and argue that a chain leader, the actor with most power in the intermodal chain can generate overall chain steering. Behzad Kordnejad [15] makes an analysis regarding stakeholders' perspectives, barriers, demands and preferences in in-depth interviews based on the principles of 'Delphi' method. Manish Verma [16] propose a bi-objective optimization framework for routing rail-truck intermodal shipments with hazardous materials, when shippers and receivers have access to alternate intermodal terminals. Woxenius [17] evaluates 72 small-scale transshipment technologies in many European countries and gives a method to evaluate them. Arnold and Thomas [18] minimize total transport costs in order to find the optimal location for intermodal rail–road terminals in Belgium. Groothedde and Tavasszy [19] minimize generalized and external costs in order to find the optimal location of intermodal rail–road terminals.

Domestic researches on IRRTS start late but a series of progress has been made. A lot of attention is paid on: (1) the current status and trend of IRRT in the world[20]; (2) search for an optimal location, operation mode[21]; (3) operation mode[22-23]. LIU Shu [20] analyzes IRRT development and advantages of America, Canada, Germany, France and Japan, and compares IRRTS of China in service provider, infrastructure construction, information platform construction and policy to seek where the blockade of Chinese IRRTS lies. LU Hai-ping [21] analyzes structure of rail freight logistics network based on the theory of structural holes and proposes the operating mechanism of the rail freight embedded in social logistics based on the networking bridge theory. XIONG Gui-wu [22] formulates an optimization model based on the graph structure for the multi-job integration with the time window, and proposes an optimized algorithm with two layers after characterizing the formulated model; the results demonstrate the formulated model and proposed algorithm are effective and feasible.

IRRTS is not some simple process like "move the freight from truck to train or train to truck" but a complex system involving various physical, social and cultural factors, which can not be solved by any single technology, but need the combination of advanced technologies and new systematic perspectives. In spite of the existing studies, there are still some problems: (1) current development mainly focuses on qualitative or quantitative research on some portion, and the comprehensive analysis of synergy, interactivity, information sharing and other social factors is missing; (2) system model is built by extracting main features of physical objects and optimized by continuous simulation and calculation, but some drawbacks can't be neglected: whether the model is suitable and the actual operating mechanism can be simulated, and the correctness and validity of the operation results can't be guaranteed; (3) communication between the physical and information system is primarily by ICT (information communications technology) and CPS (cyber-physical systems), while social factors are playing a more and more important role in the system.

The development of Internet of Thing, together with the social media enabled sharing economy have greatly changed the way people buying, selling and consuming, thus bring in the needs for supply-side reform. It further brings new challenges and opportunities to IRRTS with massive data and pervasive used wireless sensors. Both the social media data and the information system data provide materials to construct the artificial IRRTS, which modeling the physical IRRTS by using various kinds of agents to represent all types of stakeholds in an IRRTS, and defining different rules of interactions to express the complex activities involved in. After that, the artificial IRRTS can be used as a software- defined laboratory for experimenting with various scenarios in an IRRTS. The artificial IRRTS and the physical IRRTS together constitute a parallel IRRTS with dynamic feedbacks and closed loop configuration management.

III. The framework of parallel IRRTS based on ACP

The overall architecture of Parallel IRRTS is illustrated in Fig. 1.

The processes involved in the physical system include warehouse management, road transportation, rail transportation and city distribution; the objects involved include carrier, train, shipper, receiver, cargo and equipment, etc. Large-scale heterogeneous multi-source data is produced during the above processes, which can be obtained by various devices or systems that can sense, collect and transmit data. The massive data is then inputted to the artificial system, being used to study and analyze complex physical situations. Computational experiments are implemented using both real data and artificial data to compute the available options under the given situation with the evaluated success possibilities. Parallel execution is realized once human bring the computed and evaluated strategy in the artificial system into the physical system.

Agents in the artificial system are autonomous, adaptive and intelligent entities. The artificial system keeps doing two things: improves itself equivalent with the physical system through agents which are built or optimized by emergence phenomenon and interaction with physical system; evaluates solutions used for events in physical system such as emergency plan, and truck scheduling, through evaluating the interaction result of related events produced by these agents.

In parallel IRRTS, continuous interactions and mutual optimization between the physical and artificial system is realized by parallel execution. The artificial system could compute and optimize the process in the physical one through computational experiments, and outputs appropriate programs to realize route optimization, vehicle scheduling optimization and management optimization in the physical system , which in turn leading to the generation of new formatted data, and thus provides new inouts to artificial system for adjusting and optimizing its models and algorithms .

Taking freight transport for example, Fig.2 illustrate how the process works together. We describe the processes as follows. (1) Truck transport: firstly, consignor inputs freight features (involving weight, volume and transportation demand), destination and time into the artificial logistics system; secondly, the system generates order and builds related transport plan agents for suitable truck, driver and transport plans combining the inputs, weather, routes; thirdly, artificial system builds transport agent and computes the possibilities of accidents happened during the transport process; in the end, parallel system monitors and positions that process and shares with consignor and receiver to create transparent information and emergency plan. (2) Rail transport: firstly, artificial system build transshipment agent from truck to train considering carriage dispatching, freight placing, when freight arrived and staff chooses the best schedule; then, transport agent is built for monitoring and positioning; finally, transshipment agent from train to truck. (3) City distribution: artificial system builds warehousing agent and distributing agent based on distribution center condition to compute strategies considering many factors, such as when, where, way, driver and truck, then human staff select the most suitable solution for real operation. (4) Feedback process: receiver does not only confirmsto consignor but also evaluate freight status like freight damage, receiving time; besides, artificial system optimizes related agents' performance based on the evaluation.

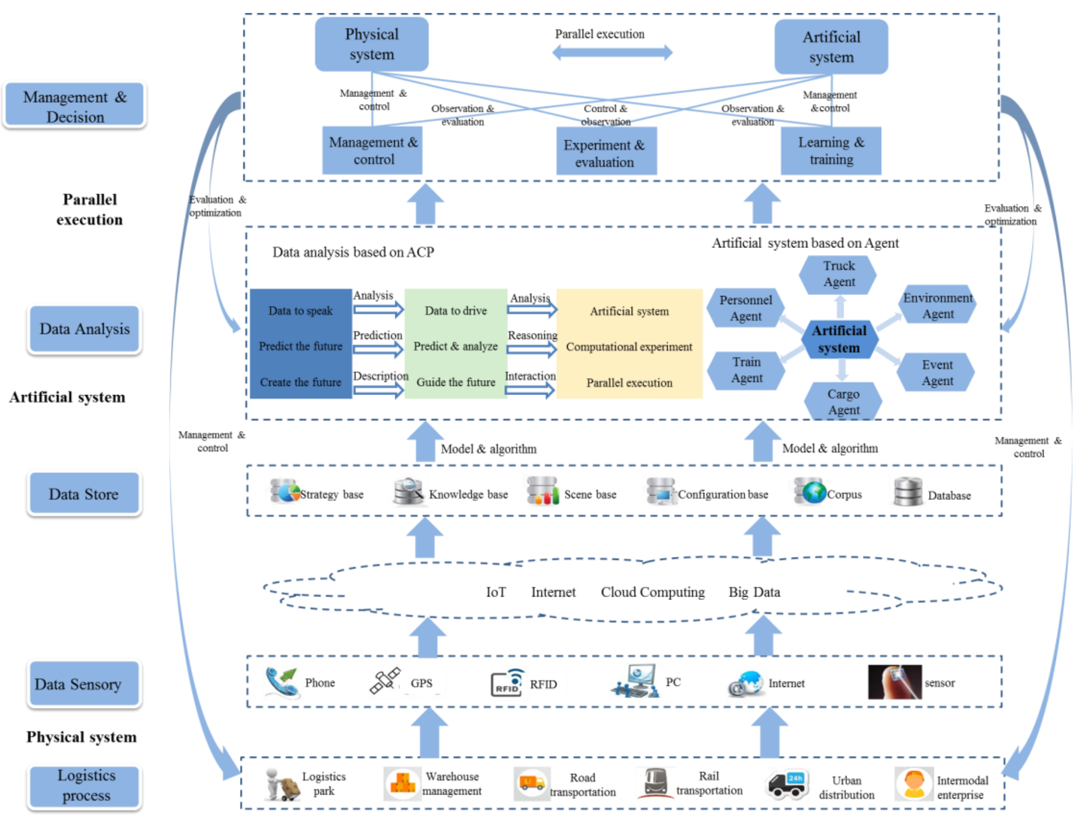

Fig.1 The overall architecture of parallel IRRTS based on ACP

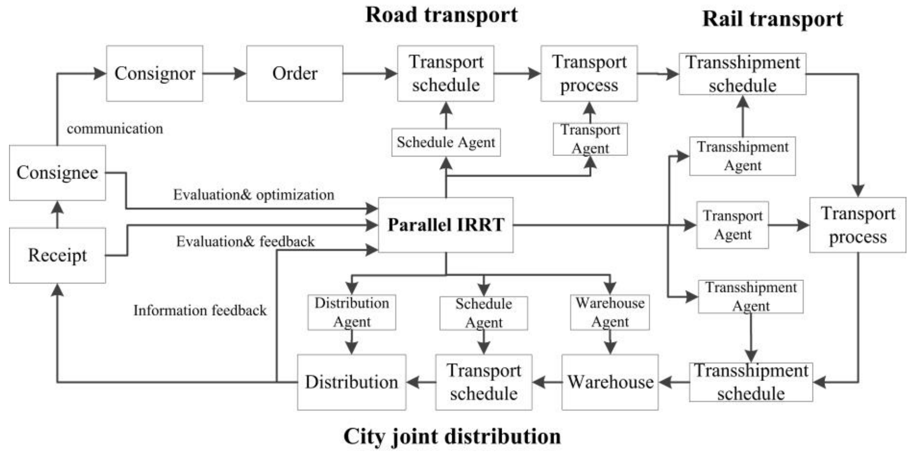

Fig.2 The entire closed-loop feedback process of freight transportation in parallel IRRTS

IV. AGENT MODEL OF ARTIFICIAL IRRTS

Agent could obtain the information around and take appropriate measures to achieve their own goals, and collaborate and communicate with other agents to achieve the collaborative goal. In general, agent has such characteristics as autonomy, adaptivity, sociability, reactivity and subjectivity. Multi-agent system provides a wonderful solution for the management and control of complex distributed system, and has been widely applied in intelligent transportation systems, aerospace and sociology studies.

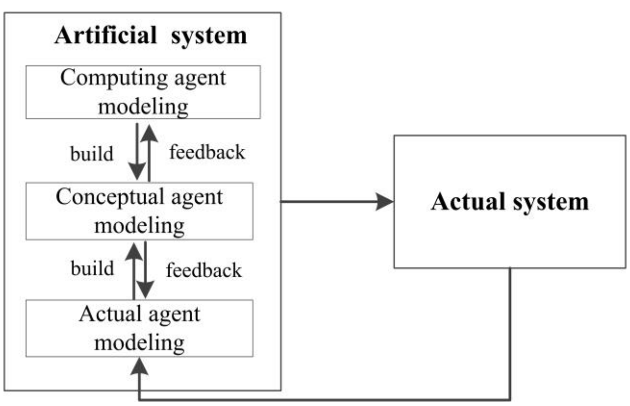

Fig.3 Agent model of artificial logistics system

Modeling of the artificial logistics system in parallel IRRTS concludes actual agent modeling, conceptual agent modeling and computing agent modeling, as Fig.3 shows. Actual agent is built via observation, abstraction and analysis on actual system objects by logistics experts and described by formula, rules and natural language, and this kind of agents are endowed with basic attributes, abilities, missions and constraint conditions. Conceptual agent is the formal description of actual agent, containing behavioral models, agent structure, and interaction mechanisms (with other agents and its environment). Computing agent is model that runs and be operated on computers. Interactions between physical and artificial system are actually the process of running, interaction, computation, test between actual agents and artificial agents.

The physical system is one typical distributed system. All the tasks are assigned to different levels for execution, so agents of each level are not only interact with other agents of this level, but also with agents of other levels. In order to make all the agents realize their own goals orderly, this paper divides artificial IRRTS system into three levels: organization, coordination and execution using the hierarchical architecture developed for intelligent control system. As seen in Fig.4, organization level mainly be on macro planning, develops and maintain agents and provides such supports as algorithms, rules and protocols. The coordination level is the interface between the organization and the execution. This level, on the one hand, receives control and management from the organization and deploys the tasks to the execution layer through the network protocol; on the other hand, it receives information from the execution and transmits to the organization. Software units in execution layer are used for deploying, replacing, managing and controlling agents to complete the detail tasks of artificial IRRT system.

In this paper, we divide the entities in artificial system into several types of agents according to their roles in the system: inter-regional agent, city agent, personnel agent, truck agent, train agent, freight agent, event agent and environment agent. Inter-regional agent belongs to the organization, city agent the coordination and the others in the bottom level.

- Inter-regional agent: the global control center of artificial system, which is responsible for inter- regional system operation and planning, collecting and analyzing information from city agent to calculate, learn, optimize and update.
- City agent: the manager of all the personnel agent, truck agent, train agent, freight agent, event agent and environment agent in one city. This agent gives detail strategies to parallel execution and communicates with other city agent or inter- regional agent.

- Personnel agent: mainly three types-logistics staff, consignors and carriers including personnel drivers and transportation enterprises. Different attributes is built because of different personnel characteristics. Personnel agent model we built can sense, learn and adjust itself according to the situation it is in. Driving years, habit, individual preference, transport route, e.g. should be considered when building driver agent while working attitude, mode, time, e.g. when building logistics staff agent.
- truck agent: involves truck type, driving factors (like acceleration, deceleration and stopping), interaction with surrounding environment. Truck agent still can think and learn to adjust driving behavior with surrounding environment.
- Train agent: contains headstock and carriage. Performance index such as power, acceleration and reliability should be considered in headstock agent while deadweight, carrying capacity, carriage type in carriage agent.
- Freight agent: mainly includes freight type, transport demand, package demand, etc. Freight agent still can think and learn to propose truck and transport demand according to surrounding environment.
- Event agent: such as carriers looking for freight, consignor looking for truck or train, planning transport route, scheduling the train, which are all described by such dynamic and static attributes as event type, when and where. Any possible event agents will be built whether they happen or not in the actual system, and they all can interact with the other agents.
- Environment agent: is built after abstracting the actual environment, obtaining its parameters. For example, working environment agent of logistics practitioners, driving environment agent, transport environment agent, social environment agent.

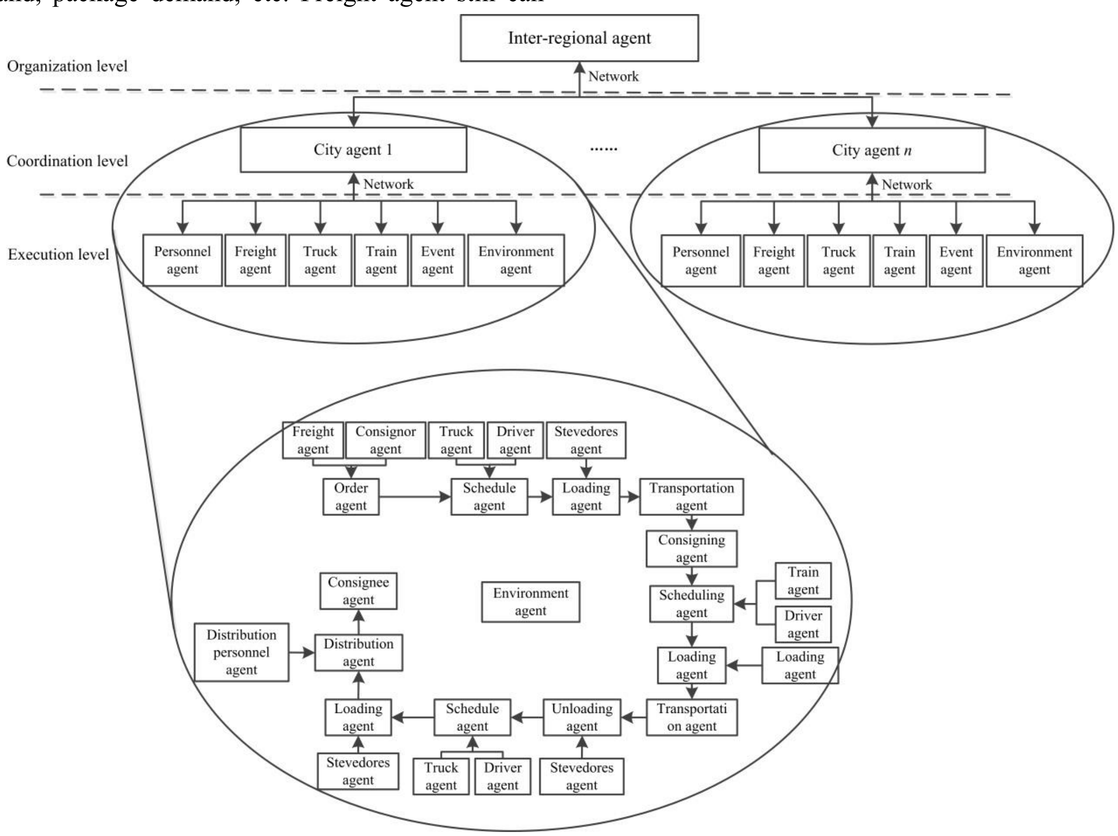

Fig.4 Artificial IRRT system based on agent

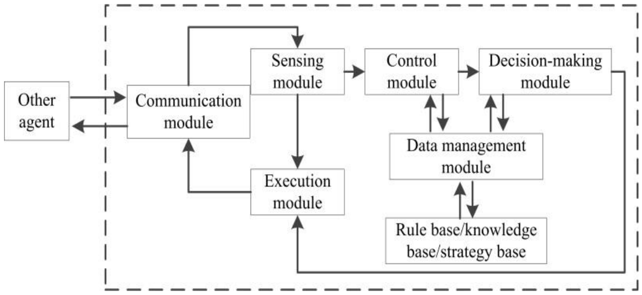

Fig.5 The inner operating mechanism of agents

Fig. 5 shows the inner operating mechanism of these agents. Communication module performs information transmission with other agents. Perception module converts the perceived information to the standard information that the agent can recognize. Execution module reflects according to the standard information and the current status of the agent. In the control module, agent plans according to the control rule, its own knowledge and the current state, and submits the decision module to form the final control strategy, thus driving the executive module to reflect. When the agent is processing information, whether control module and decision module is needed depends on the complexity of the perceived information. These modules in each agent are set according to its own position in the system and all these agents build artificial system by their interaction with each other.

V. CONCLUSION

In this paper, a parallel IRRTS framework is proposed based on ACP approach. A physical system corresponded artificial system is constructed applying multi-agent modeling, which takes freight transport for example to show how parallel IRRTS works. Eight types of agents are designed considering the entities included in an IRRTS. Whereafter the system operation is tested and computed through the interaction among all types of agents. Complex factors including social, physical and operational elements are considered in the parallel system, which provides new leverages for optimized transport scheduling, customized transport services, thus enables IRRTS to operate with high efficiency and low cost. This research is supported by the National Natural Science Foundation of China (No. 71472174, 61533019, 71232006, 61233001).

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