The Construction of Parallel Systems of Subway Stations based on ACP Approach

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***Abstract*—The research on crown behavior and evacuation laws in the case of unexpected emergency incidents such as fires, explosions, accidents, driving, man-made mistreats in relatively closed, personnel-intensive, and high-risk subway stations, have a good theory and practical significance. Based on ACP approach, the architecture of universal artificial system of subway station is put forward for the first time. And its construction process and its application and significance are provided. It can study crowd behavior and evacuation laws in subway stations in the case of emergency situations. It may provide technical support for designing subway stations, evaluating evacuation plans and training security management and personnel. And, it has also good theoretical and practical values in designing evacuation system, developing and optimizing evacuation plans.**

Keywords—subway stations; artificial systems; acp approach; parallel systems

I. INTRODUCTION

With the increasing size of the urban population, and the growing demand for travel, subways, because of their advantages such as high-speed, safety, punctuality, low consumption, environmental-friendly, all-weather, high-capacity, saving ground resources, has become the first choice of the world's large-scale urban public transport. The rapid development of the metro, greatly eases urban traffic congestion condition, and plays an irreplaceable important role in the social life, economic activities and public activities.

Subway stations are the most important parts of subways, and have their own objective characteristics, including narrow enclosed spaces, intensive personnel, complex structures, long-distance evacuation exit, limited lighting and ventilation equipment, etc. The emergencies in subway stations can easily result in a large number of casualties and economic losses and very bad social influence. In recent years, there are many accidents caused by congestion, fire, explosion, engineering, human factors happened in the subway stations in different countries.

Simulation technology is widely used in the study of human behaviors and the field of emergency evacuation. But, most simulation softwares, based on the assumptions of mathematical models, are often difficult to achieve the reproduction system in a variety of scenes and descriptions, and also very difficult to communicate between the simulation softwares and modules, which make the description of complex systems local and limited. The subway is a complex system composed by people, vehicles, routes and equipment, involving economic, social, ecological, environmental, climatic, and human factors. So, it is difficult to fully describe this complex system via single simulation software. ACP approach, mainly consisting of Artificial systems (A), Computational experiments (C) and Parallel execution (P), which is based on holism and complex system theory, has its specific advantages in the research on the modeling and analysis of complex systems [1-3]. It has been well applied to transportation system such as high-speed rail systems[4], urban rail systems [5-7], general transportation systems [8-10], public traffic in major-typeactivities [11,12], urban transit systems [13], BRT [14], and other systems like chemical production [15], power systems [16], and aerospace[17], etc.

Based on ACP approach, this article will provide the construction framework of general artificial system of subway stations, to study crowd behaviors and evacuation laws in the case of emergency situations.

II. RESEARCH STATUS AND PROBLEMS

Science the first subway was put into operation in 1863 in London, the subways have been becoming the first choice of public transportation in major cities in the world with their unique advantages [1]. Now, hundreds of cities have built subways [2].

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The subway is a large complex system, involving almost all engineering disciplines, and the economy, population, resources, environment and other social sciences. Its operator safety, efficiency are the focus, which has important social significance, economic and political significance. However, there are many emergences in recent years and a large number of casualties have been caused. For example: in 2003, in Daegu South Korea, fire led to 198 people killed and 289 injured; in1999, in Belarus, congestion led to 54 people trampled to death; in 2005 in Paris France, fire caused 19 deaths; in 2011, in Shanghai China, rear-end accidents led 295 people injured, and so on.

These accidents caused heavy casualties, mostly because these were caused by fires, accidents, poison, explosion, crowded or human errors, and the location were in the subway stations. Subway stations have their characteristics, including intensive people, limited space, the limited time available to safe evacuation area, which often ultimately result in heavy casualties. The accidents in subway stations can not only threat safety of life and property, cause huge economic losses, but also lead to social chaos. Therefore, the research on modeling and simulation and evacuation laws of subway stations has profound theoretical and practical value.

The conventional research methods include mathematical analysis and computer simulation. Mathematical analysis, based on network flow optimization theory, taking different individuals or crowd as the fluid, model crowd with fluid mechanics and thermodynamics model. The main drawback is ignoring the difference of individual behavioral in the evacuation process, which result in that the evacuation process does not match with the actual. The computer simulation can compensate for this shortcoming. Rapid development of computer technology greatly advanced simulation study of traffic flow, providing the conditions for emergency traffic evacuation simulation. But, this computer simulation assumes that human is rational in emergency situations, and completely carrying out smoothly as planned, and there are no accidents in the implementation of evacuation plans. These are clearly inconsistent with the actual.

III. Construction of Artificial Systems in Subway Stations based on ACP Approach

A. ACP Approach

Complex systems involve two aspects: engineering complexity and human complexity, which makes the traditional mechanism-based modeling approach be no longer applicable. Meanwhile, the research on human factors in complex systems of complex systems are mainly using experience, because there are lacking of effective modeling and analysis tools. Therefore, how to construct novel model systems modeling complex systems, which can consider the engineering complexity and human complexity simultaneously and reflect the difference from the traditional simulation system, to carry out quantitative evaluation of evolution and learning, is a very key scientific issues.

ACP approach is a coordinative research and systematic effort to model, analyze, and control complex systems, which are difficult or even impossible to be deal with by traditional methods [1-3]. Basically, ACP approach consists of three steps: modeling and representation with artificial systems; analysis and evaluation by computational experiments; and control and management through parallel execution between actual and artificial systems [1]. Clearly, such transportation systems as subway systems are suitable for ACP approach. However, the motivation for employing ACP approach here is mainly due to the lack of timeliness, flexibility and effectiveness of the existing transportation simulation systems [8]. Artificial systems are a very good solution. And, those experiments, which cannot allowed on the actual systems due to ethical, legal, economic and other reasons, can be tested in artificial system platform. By computational experiments, the behavior of complex systems can be predicted and analyzed. Finally, parallel execution of actual systems and artificial systems can be implemented by using the results of computational experiments.

B. The Universal Artificial Subway Stations

Based on ACP approach, taking into account the engineering complexity and human (social) complexity, according to the characteristics of the subway stations, the universal artificial subway stations can be constructed, including computing experimental platform, and comprehensive assessment system, to study crowd behavior and evacuation laws in the unmoral circumstances to research and analyze evacuation systems, evacuation bottleneck, evacuation plans, etc., and provide decision support. The main contents include:

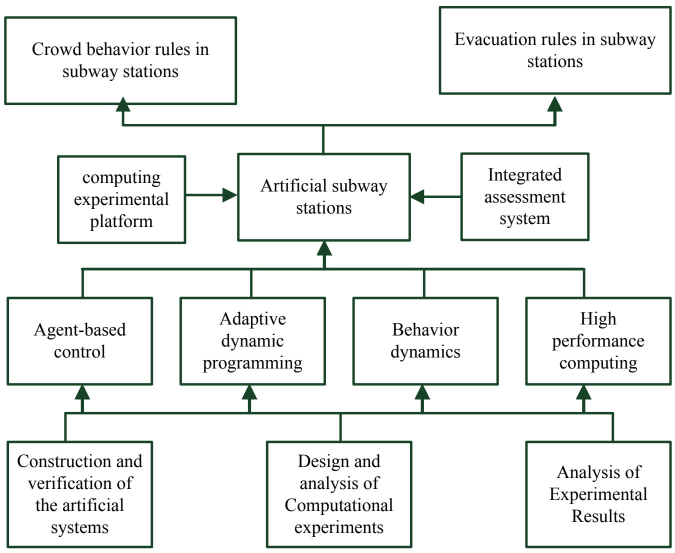

Fig.1 The construction and application of artificial subway stations

1) Equipment agents

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) overhaul security system modeling: including environmental monitoring systems, air conditioning systems, ventilation system, fire control systems, emergency escape route, drainage system, water supply and drainage systems, and security systems.

c) monitoring units: Radio Block Center, Computer-Based Interlocking, Train Control Center, the dispatching system, microcomputer monitoring, etc.;

2) Personnel agents

a) on-train personnel: drivers, mechanics, conductors, crew, passengers, etc.;

b) passengers modeling: considering macroscopically crowd size, time distribution, spatial distribution, peak flow, etc. considering microcosmically individual differences and the impact of the quality of personnel, habits, mood 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 subway stations model is constructed by infrastructure facilities and tracks, 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. The environment of the artificial system mimics the real environment of the actual system, from which the influences of the operating environment 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.;

The whole model of the artificial system 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.

C. The Credibility Verification

As mentioned above, the first step of the application of ACP approach is the modeling and representation of the artificial system, a lot of intelligence means can be used to establish the artificial system, just like agent-based modeling object-oriented programming, Petri nets, linguistic dynamic systems, cellular automata and their generalization and so on. But whether the artificial system can represent the actual system or not is still a question.

So after accomplishing of the artificial subway station, the validation of credibility must be done. The validation of credibility plays the role as a judge in the establishment of the parallel system; which indicates how the artificial system is similar with the actual system in the aspects of behaviors and functions. If the credibility validation result indicates that the artificial system is acceptable, the computational experiments and parallel execution can be done in the following stages, if not, modifications of the artificial system are needed.

The credibility validation is the key step of the establishment of the parallel system; it determines whether the artificial system can be used to do computational experiments and to control and manage the real systems.

The artificial subway stations are modeled by agent-based technology, so every element in the actual system is represented by an agent in artificial system, like the trains, the passengers, and the traffic environment and so on. The process of the credibility validation of the artificial system includes the following three steps:

1) The credibility validation of single agent

To select some agent indexes which are easy to be observed and can describe the agent inside state; then to valid the function of the agent by the indexes' values measured in the artificial system to get the credibility validation result of the function and macro-behaviors of the agent.

a) equipment agents. Equipment are the core parts of the whole system, so equipment agents modules need to remain fully consistent with the actual equipments, including the number, features and principles, etc.;

b) personnel agents. Mainly including two classes: the staff and passengers. The staff has a weaker effect, only pursuing the local approximation to the actual environment. But passenger agents are the central concerns;

2) The credibility validation of subsystem

To Take the agents which included in the subsystem as the subsystem's indexes, their credibility validation results will be set as the values of the indexes.

3) The credibility validation of the whole system

To Take all the subsystems as the system's indexes, their credibility validation results will be set as the values of the indexes, and then the credibility validation of the whole system will be done using the same method that was used in 1) and 2).

By the credibility verification, the global behaviors emerging bottom-up from artificial system can be ensured to be consistent approximatively with the actual system.

Through the adjustment and optimization to the defects in the artificial system, and the correction of the specific parameters of the corresponding individual or agents, the effectiveness, rationality and authenticity of the artificial system can be ensured, ultimately to br equivalent to the actual system.

C. The Construction Process

Based on ACP approach and Multi-Agent modeling method, universal artificial system of subway stations can be constructed as follows:

Step 1: to build universal artificial subway station systems using the combination of the mechanism and data modeling, i.e. to construct related correspondent agents of passengers, subway running system, passenger services system, overhaul security system, operating environment, social environment, climate environment, etc.

Step 2: based on agent theory and multi-agent coordination methods, to build different agents and their related environment and the rules, to form agent model library. At the same time, using language dynamics theory to effective utilize information in language level, to build the connection of knowledge of human language and computer digital knowledge, to reduce the complexity of the system description.

Step 3: to construct computational experiment platform and comprehensive evaluation system, ultimately to build completely universal artificial subway station systems.

Step 4: for "deviation" of the artificial and actual systems, to use data mining, intelligent recognition methods to extract the characteristics of subway stations, and to assess, verify, adjust based on Agent-based man-machine interactive methods, to rolling optimize the artificial system. Then, to verify and amend the artificial systems in three stages: single agents, subsystems, and the whole system.

Step 5: to design comprehensive assessment system: to confirm indicator weight of different system levels using analytic hierarchy process, to quantify qualitative indicators by expert analysis methods which are not easy to be accurately quantitative analyzed, then to get dimensional transformation of each indicators, finally to handle every indicators based on fuzzy comprehensive evaluation method.

Step 6: to develop computational experiment platform by the application of intelligent optimization methods, including genetic algorithms, simulated annealing, ordinal optimization, then to design "test" program to analyze the crown behavior and evacuation laws in subway stations. Based on the computational experimental process, the artificial system 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.

Step 7: From psychological, behavioral, cognitive, action ability etc., character, psychological, age, gender, safety awareness, and other personal factors as well as population density, population mental state and action crowd factors that impact on the evacuation of the subway stations are researched, and their laws are summarized to provide the basis for the simulation of the behavior rules, trying to verify and correct the artificial systems and more accurately describe the subway station personnel evacuation behavior. And, evacuation systems, evacuation bottlenecks, and evacuation plans can be analyzed, optimized, and improved by computational experiments. Main evacuation impact includes: evacuation number, different crowd behavior characteristics, different crowd roles, different decision, physical environment, dynamic environment, etc.

Step 8: A complete parallel execution system between the artificial systems and actual systems can be constructed, which is capable of controlling the actual systems through real-time supervision and adjustment. The parallel system can guarantee that the artificial systems' suggested optimal solution runs continuously, therefore improving the real operation's reliability, safety, and efficiency.

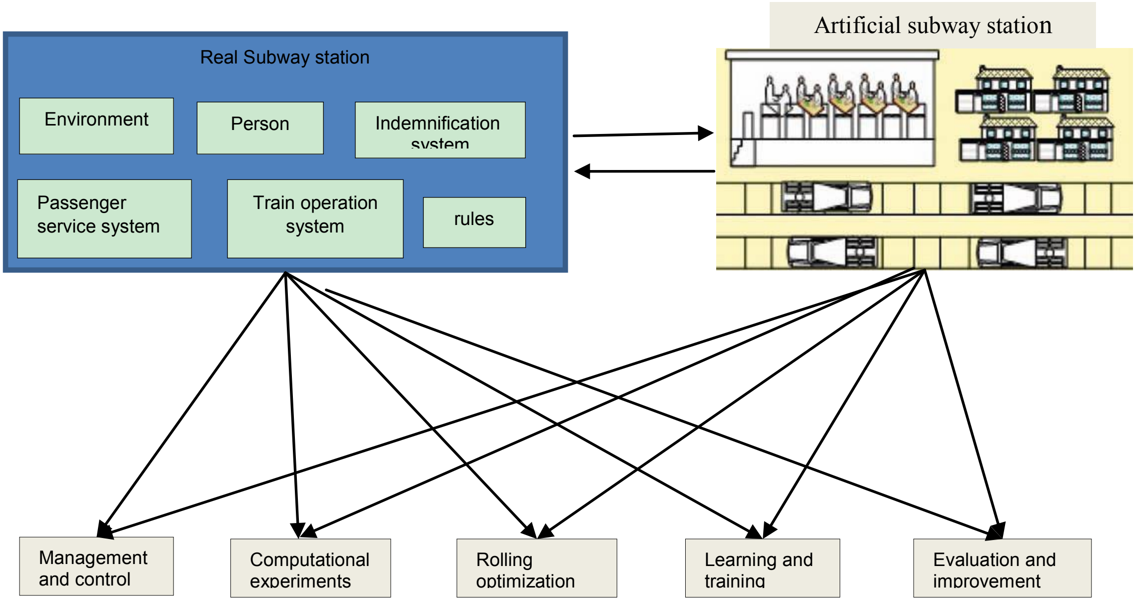

Fig.2 The framework of parallel subway stations

D. Application and Significance

Fig. 3 The 3D show of artificial subway stations

Therefore, artificial subway stations can neatly simulate the crow behavior and evacuation process in different scenes and situation. It can summarize, simulate, and research crowd behavior in normal circumstances and analyze evacuation laws, i.e. through computational experiments platform and comprehensive assessment system, to study impact of the psychological, behavioral, recognized knowledge, cognitive ability, operational capacity, performance phenomena, reaction, behavioral characteristics, cognitive and decision-making, clustering phenomenon, flow and retention, panic factors, etc. and to analyze the influence of number, behavior characteristics, different psychological reactions, physical environment, evacuation logo, evacuation drills, evacuation systems, evacuation bottleneck evacuation plan analysis, finally to assess various evacuation plans and give improvement suggestions. It can be predicted that the research will provide technical support, for the design of the subway stations, the evaluation and optimization of the evacuation plans, staff training, the design of evacuation system.

IV. CONCLUSION

In this paper, based on ACP approach, taking into account social, natural, engineering, and cultural aspects, the framework universal artificial system of subway station is put forward for the first time. Based on multi-agent modeling， artificial subway station that is consistent with realistic operations of actual subway station is first constructed. Then, different kinds of computational experiments are performed on the artificial subway station, followed by analysis and synthesis. Finally, through an interactive and parallel operation between the actual and artificial subway station, a set of practical control and management strategies can be achieved for the actual subway station. Based on parallel subway stations crowd behavior and evacuation laws in subway stations in the case of emergency situations can be studied. And, technical support can be provided for designing subway stations, evaluating evacuation plans and training security management and personnel. And, it has also good theoretical and practical values in designing evacuation system, developing evacuation plans, and evacuation organization.

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