Parallel Transportation Management and Control System for Subway Systems based on ACP Approach

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Abstract—**This paper presents a framework of Parallel Transportation Management and Control System for Subway Systems (PTMS-Subway) based on ACP approach. Firstly, based on multi-agent modeling, Artificial Subway Systems is constructed. Then, the design, content, and process of Computational Experiments Platform are performed. Finally, through an interactive Parallel Execution System between the actual and artificial subway systems, a set of practical strategies of management and control can be achieved. PTMS-Subway can improve the reliability, efficiency, safety, and service level of subway systems.**

I. INTRODUCTION

Since the first subway was built in London in 1863, subways have become the first choice of developing public transport in world's major cities, because of their high-loading with low energy consumption, safety and reliability, fast and comfort, and other unique advantages. However, the subway is actually a dangerous transport mode. Travelling generally in the enclosed space underground, once emergencies events happened, the subway is often associated with unpredictable casualties and property loss. Therefore, how to ensure the safety and reliability of operation has become an important subject in the research and development of subways.

Nowadays, simulation technologies are becoming more widespread in the research of metro areas. Also, a lot of simulation software has been developed and applied to the planning, design, and management of subway construction. For example, VISION for analyzing the duration of trains and capacity of lines, LOGSIM for train scheduling and traffic control, OPENTRACK and RAILSYS for optimization of train scheduling, LEGION and EVACNET for evacuation [1, 2]. Other typical rail simulators include NUCARS, ADAMS/RAIL, RAILSIM, RAILPLAN, TRAINSTAR, TOM, MEDYNA, NUCARS, SIMPACK, SIMSYSTEM, etc.

But, the aforementioned simulation platforms focus only on some specific aspects of subway systems. And, they are based on mathematical models and the assumptions of the actual systems, which make the lack of authenticity. Because of the limitation of accuracy requirements of modelling or simplicity requirements of calculation, the traditional simulation systems cannot reproduce and describe most factors or scenes of actual subway systems. However, to get the most realistic simulation results, a novel simulation system which can take all factors of the actual system into account is essential.

ACP approach, integrating Artificial Systems, Computational Experiments, and Parallel Execution, is a novel approach to model and simulate real complex systems [3-4]. Nowadays, ACP approach has been used in the management and control of transportation system [5-10], Large-scale activities [11, 12], emergency management [13, 14], and other fields [15, 16].

In this article, ACP approach is applied to design and build Parallel Transportation Management and Control System for Subway Systems (PTMS-Subway). Firstly, considering the various factors of actual subway systems, using agent modeling method and large-scale computer modeling techniques, the "equivalent" Artificial Subway System (ASS) can be constructed; then to understand and asses the interaction of the elements of the actual system in normal and non-normal state via Computational Experiments Platform (CEP); finally by using ASS to learn more about the ever-changing laws to optimize control and management, finally to optimal actual subway systems by Parallel Execution System (PES).

II. ARTIFICIAL SUBWAY SYSTEM (ASS)

The construct of ASS is not restricted by precise mathematical model, and the "equivalence" of system functions and behaviors is taken only into consideration. Considering various factors such as personnel, equipment and the environment, ASS is divided into seven modules (see Figure 1). Each module can be broken down into smaller components in accordance with the requirements of research objectives. These different components and modules have autonomy, interaction, and learning and adaptive capabilities.

A. Train Running System

- Subway lines: including the type (rail line, branch line, auxiliary lines, reentrant line, temporary stop line, crossing line, contact line, etc.), name, direction, length, line level, line type, maximum slope, curvature radius, line spacing, interval division, site

distribution, slope and radius, speed limitation, and other attributes, etc.
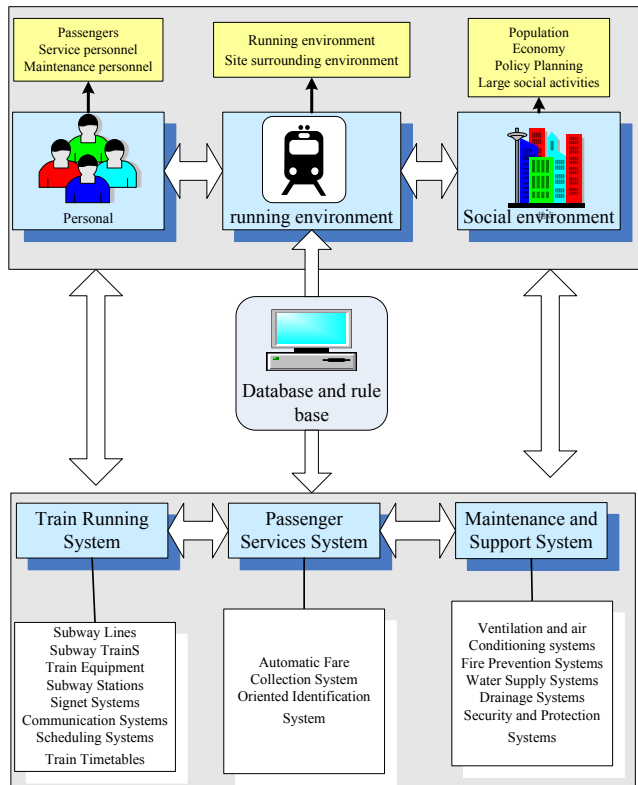

Figure 1. The framework of ASS

- Subway trains: the line, the number, number of seats, length, width, maximum speed, sticking coefficient, drag formula, traction/speed curve, axle load, grouping, traction and braking distance and other attributes, etc.

- Train equipment: transponder information transmission module, speed and distance measurement module and wireless communication module, etc.

- Subway stations: name, location, number of entrances, spatial structure, the largest passenger throughput, etc.

- Signet systems: signal, switch machines, track circuits, interlocking system and Automatic Train Control (ATC) system, which includes Automatic Train Protection (ATP), Automatic Train Operation (ATO), and Automatic Train Supervision (ATS), etc.

- Communication systems: communication transmission systems, telephone systems, scheduling systems, clock systems, CCTV systems, broadcast systems, and passenger information systems, etc.

- Scheduling systems: artificial dispatching systems, centralized electronic dispatching systems, and automatic train operation system, etc.

- Train timetables: train graph, turning around time, and track utilization scheme, etc.
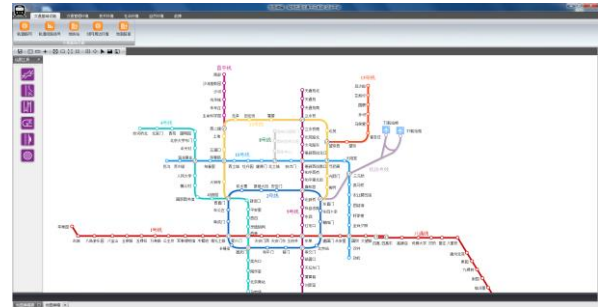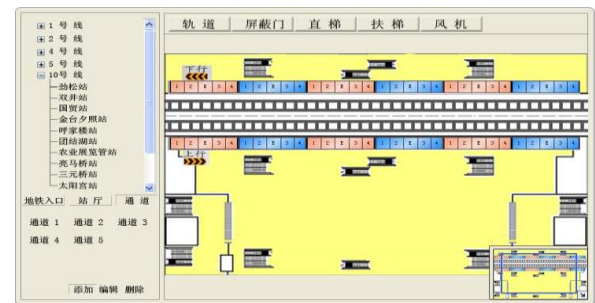

Figure 2. Subway network of ASS

Figure 3. Subway station of ASS

B. *Passenger Services System*

- Fare Collection (AFC): ticketing systems and automatic ticketing system, automatic fare collection system, etc.

- Oriented identification systems: various types of orientation signs, prohibition signs and other signs. This system provides the guide identifies information leading passenger entering or leaving the station and getting on the trains, etc.

C. *Maintenance and Support System*

- Ventilation and air conditioning systems: to ensure air quality of stations and underground tunnels, including air environment, temperature, humidity, and air velocity, etc.

- Fire prevention system: fire alarm systems and gas extinguishing systems.

- Water supply system: domestic water supply system, fire hydrant water supply system, water sprinkler systems, air conditioning cooling water circulation system, etc.

- Drainage system: to deal with fecal sewage, seepage water, and stormwater, etc.

- Security and protection systems (SPS): video surveillance and control system (VSCS), access control system (ACS), security management system (SMS), surveillance and control center, alarm receiving centre, and protective area, etc.

D. Operating Environment

- Running environment: the tunnel inherent characteristics.

- Site surrounding environment: the surrounding buildings, including site characteristics, institutions, shopping malls, hospitals, commercial and industrial areas, etc.

E. Personnel

- Passengers: macroscopically considering factors include flow size, time distribution, spatial distribution, the peak flow periods of time; microscopically include the quality of personnel, habits, feelings and individual differences, etc.

- Service personnel: drivers, mechanics, pickers, fare collectors, conductor, station staff, etc., involving not only the quality of personnel, habits, mood and other individual differences, but also includes service attitude, professionalism, management methods and institution, etc.

- Maintenance personnel: track construction, signaling equipment maintenance personnel, technical engineers, track personnel, brakemen, operational duty personnel, depot maintenance personnel, signal equipment maintenance personnel, etc.

F. Social Environment

- Population: the population factor is the decisive factor in the planning of subway lines and the location of subway stations, etc.

- Economy: The development of economy and subway has mutually reinforcing effect. The subway can increase traffic, provide business opportunities. And the economy development can promote the development of the subway, etc.

- Policy Planning: national policy and urban planning for the subway development has a very important role. Firstly, the subway is a social welfare program, so the country's overall plan plays a key role. Secondly, the subway construction plays also huge role for the overall city planning for to solve the current needs and the long-term planning, etc.

- Large social activities: The subway is as the main transit mode of large social activities, etc.

G. Rule Base

- The basic elements of train control system: work mode, operating rules, scheduling rules, traffic rules, temporary speed limitation and interlock programs, etc.

- The inherent performance, operating manuals of trains, lines and other equipment, as well as railway stations, bus services segment and other inherent institutional management rules, etc.

- The staff management system, assessment standards, technical indicators, practices, etc.

- The command and management files of the relevant government departments, the relevant national standards and industry standards, etc.

III. COMPUTATIONAL EXPERIMENTS PLATFORM (CEP)

CEP is as a repeatable test platform, and it is also a scenario generator that can create real and virtual experiment scenes simultaneously. CEP accepts scenario input directly from end-users or scenario library. After instantiating related scenario interaction mechanism and control rules, data is forwarded to the event-driven simulation engines. Simulation results are saved in chronological order to facilitate the analysis of the relation between triggering events and triggered events in the experiment.

To describe the mutual interaction between object models and their influences, CEP needs a large number of experimental sections of analysis and calculation method, which make a big difference between Computational Experiments and traditional simulation.

CEP can achieve the process of implementation, revisions and re-implementation during the experimental program, which is cost-effective. CEP can evaluate the test results of different schemes, including the validity of operation scheme under different passenger flow distribution, the rationality of the emergency management solutions, and the profitability of the subway route planning, etc. The evaluation methods include expertise evaluation, quantitative and qualitative assessment, and fuzzy evaluation. It can provide strong guidance for actual subway systems, greatly improving their management efficiency, train operation safety, and service quality, etc. For example, if the route has been determined, its security, efficiency, service quality and contingency plans can be analyzed and assessed; if the route is in planning stage, the route making and the analysis of alleviating traffic pressure can be evaluated.

A. CEP Design

The most important aspect of Computational Experiments is the design of CEP. During Computational Experiments, ASS is as a repeatable test platform, and the events are as a program library, which include a variety of controllable or uncontrollable factors. All experiment programs, calculation data, and evaluation parameters are needed to be recorded and filed to build appropriate libraries of programs bases, databases, and database management systems, to provide data support for subsequent repeated trials and Parallel Execution. CEP includes the following modules:

1) The environment settings (before experiments), including urban planning generator, management generator and environment generator, and some experimental scene generator.

a) Urban planning generator: including traffic infrastructure settings of staff, trains, and roads, infrastructure planning unit (subway network, stations and surrounding environment information), population information (population distribution, population activities, travel options, etc.).

b) Management generator: including railway timetable, departure intervals, train scheduling, temporary speed limits and other traffic management information, etc.

c) Environment generator: including weather generator, accident generator, and large-scale activities generator, etc.

d) Experimental scenario generator: including different experimental scenes generated according to above three generators, etc.

2) Experiment simulator (generating experiments): to establish experimental conditions, and generate different experiments scenes.

a) Select the type of experiment, including global experiment, and local experiments.

b) Select experimental scenes and conditions.

c) Select experimental methods, including uniform experiments, orthogonal experiments, and random experiments.

d) Generate experiment list, where all experimental data can be shown.

e) Experimental operation, to start the experiment, and display each progress.

f) Experimental results display: including information statistics, animation playback, etc.

3) Evaluation and analysis of experiments results (after experiments).

a) Evaluation indicator system: to specify different application types of assessment and integrated system of indicators.

b) Experimental results evaluation: to offer a wide-ranging evaluation system from technology, economy, environment, social and urban development, traffic regulations, incident management, etc.

c) Experimental results analysis: to analyze the traffic influence of different experimental conditions under Evaluation indicator system.

d) Experimental results analysis knowledge base: to output and store experimental analysis report.

B. The contents of Computational Experiments

1) The optimal strategy evaluation in daily operation

In terms of train operation, departure intervals, overspeed protection, temporary speed limit, the optimal selection of inertial points, speed-distance curve, energy saving and emission reduction, and so on, are included. In terms of passenger services, route marking, equipment implementation, sanitation, hospitality services, fare collection system, and transit signage, and so on, are included. In terms of maintenance support system, route security guarantee maintenance, track equipment maintenance, station equipment, power supply facilities, and so on, are included. In terms of organizational planning of the train operation, the staff formation, the adjustment of the operation chart, and so on, are included.

2) The experiments of passenger emergence

To analyze the characteristics of passenger flow in subway systems, and forecast and evaluate the time, the location, and degree of passenger emergence, then to develop appropriate management measures.

3) The experiments of subway route planning

The construction of subway is very expensive. Then the planning of a new route needs to consider various factors. The main factors include: the aims of the line, the direction of the main passenger flow, the construction of the subway network, as well as the future and recent of the urban development. Based on CEP, the impact of various programs, including the mitigation capabilities of passenger pressure, the impact on the surrounding environment, the construction conditions and interference, the operational efficiency, can be predicted and analyzed.

4) The experiments of emergency and their knock-on effects

Unexpected emergencies include: natural environment factors, improper operation, health and safety accidents, social stability, etc. The group behaviors emerged in these events can be fully reflected on CEP to provide prediction and suggestion of management implementation.

C. The process of Computational Experiments

The process of Computational Experiments is as follows:

1) Analyze clearly the research subject, target content, sector participation, participation functions and staff responsibilities, etc.

2) According to the key sectors and the main participants involved, develop a variety of experimental programs, and establish a logical and physical framework of the program model.

3) Conduct experiments scenes: set urban planning generator, management generator and environment generator, and some experimental scene generator, and select database, data management server, algorithm, urban planning data, management data, environment data, scene data, and hardware and software interface.

4) Set experiment simulator, and find controllable and uncontrollable factors according to the analysis results, adjust the parameters and settings of the appropriate personnel and equipment, and improve the scheme deficiency.

5) Repeat the process until the optimal solution or the program that the actual system can withstand.

6) Evaluate, analyze the results and decision making.

7) Repeat the process until the optimal solution can be gotten. And store and analyze the operation results.
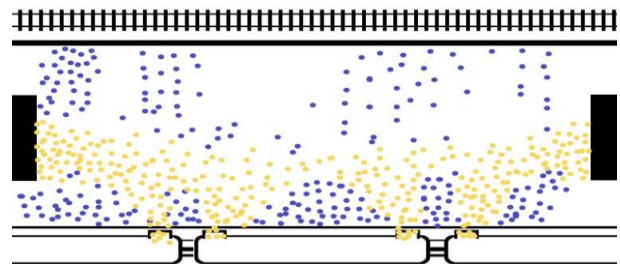

Figure 4. The evacuation at a subway station display of CEP

D. Parallel Execution System (PES)

PES can execute the final results obtained from CEP and ASS in actual subway systems, and input the feedback to ASS, finally to achieve moving optimization. By real-time monitoring the actual system to grasp its state changes, PES can adjust online the optimal solution running on ASS by the testing and evaluation of CEP constantly, eventually to achieve the purpose of timely developing control and management program that is appropriate to current running state of subway systems. Through PES, the real-time and effective management and control of actual subway systems can be realized. Then, the traditional technical control can rise to integrated control system combined with management to approve the safety and efficiency of subway systems.

In the course of PES, the status of ASS is equivalent to the actual system. In the actual system, the selections or improvements of the solutions are based on the results of the assessment of ASS. According to the evaluation results from CEP, the effective solutions can be found to provide reference for the control and management of actual subway systems. Then, ASS can be applied from passive to active, from static to dynamic, from offline to online, from subordinate to the equal status to fully play its role. So, PES is bound to have an important significance of secure, efficient and low-cost operators.
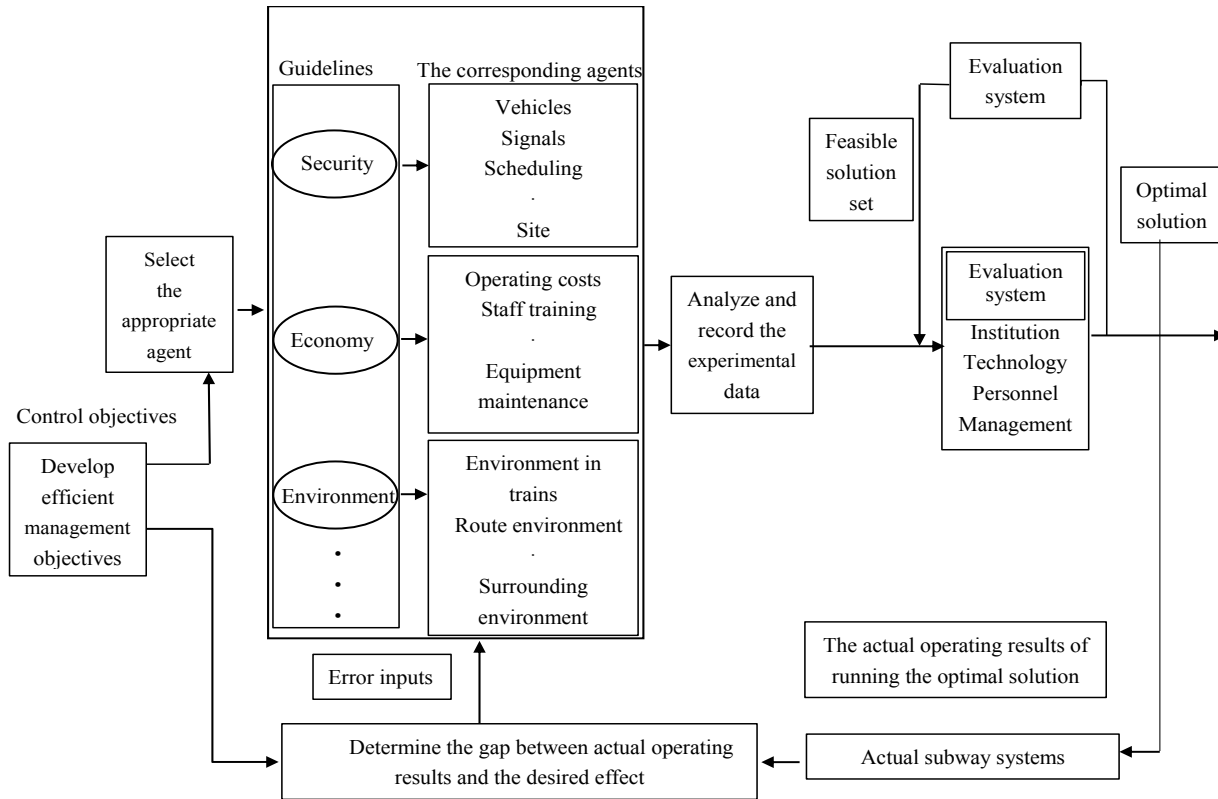

Figure 5. Parallel execution of urban rail management schem

The Content of PES includes:

1) Parallel Management Systems (PMS)

a) a) The management and control of individual units in subway subsystem: take the decomposed independent units of each subsystem as the object, such as power supply unit, control unit, communication unit and so on, the corresponding units can be managed and controlled efficiently.

b) b) The management and control of subway subsystems: take subway subsystem as such as train control systems, equipment unit, station signal system, station personnel management and so on, the corresponding subsystems can be managed and controlled efficiently according to the actual requirements of the control targets.

c) c) The scheduling and management of subway systems: take subway lines or subway network as the object, the running trains, equipment and all involved personnel (managers, drivers, and passengers, etc.) can be managed and controlled efficiently, to achieve the operational goals of safety, high-efficiency and energy-saving.

2) Parallel Training Systems (PTS) for training management personnel, including control optimization in normal operations, and disposition under unusual circumstances.

3) Parallel Evaluation Systems (PES) for employee management, including operating optimization, program generation, evaluation, display, execution, analysis, optimization, etc.

4) Parallel emergence Management Systems (PeMS)

a) a) Emergency training and drills

- By training scenarios based on CEP, PeMS can train different staff, including their psychological quality and responsiveness under normal conditions and

emergency situations, and help them be familiar with the emergencies processing and their commitment.

- Through repetitive reproduction scenes, to improve their level of handing emergency, and to make them to respond effectively all kinds of emergencies.

b) b) The verification of emergency plans

- In the process of developing contingency plans, their feasibility and effectiveness can't be directly verified, but via ASS and CEP, by setting scenes, the feasibility and effectiveness of emergency means under various types of extreme situations can be verified to provide reference for selecting the means of emergency.

c) c) The assessment of emergency programs

- By CEP, PeMS can verify the completeness, operability, effectiveness, economical efficiency of the designated emergency plans.

d) d) Emergency Management and Control

- PeMS can realize the interaction and collaboration of the actual and artificial subway systems, to improve the level of crisis management.

- PeMS can predict the dynamic evolution of emergencies, and optimize the emergency measures, reduce emergency disposal in loss of life and property.

IV. SUMMARY

Based on ACP approach, the framework of Parallel Transportation Management and Control System for Subway Systems (PTMS-Subway) is proposed. The components and function of PTMS-Subway – Artificial Subway Systems, Computing Experiments Platform and Parallel Execution System – are introduced and described in detail. PTMS-Subway can improve the reliability and safety of subway systems, and enhance their quality of services.

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