

# Emergency management of urban rail transit systems using parallel control

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## Abstract

This paper presents a parallel control system designed for managing emergent events in an urban rail transit system (URTS). The key features of the system include cloud computing, information fusion and expert systems. A multi-agent approach is used for modeling diversities and interactions in the URTS. Partially due to its ability to interact with the real system via parallel execution, such a parallel control system would provide a cost-effective solution for emergency personnel training, verification of emergency measures, and validation of emergency plans and management policies.

*Keywords: emergency management, urban rail transit, parallel control.*

## 1 Introduction

As a convenient transportation mode, urban rail transit systems (URTS) have gone through a booming development phase and are getting more and more popular today, which also implies that more attention should be paid to emergency management of URTS since emergency incidents happened in URTS can cause huge humanitarian, social and economic losses if no proper and timely responses are taken. An incendiary case happened in the subway system of Daegu, Korea in 2003, resulted in 198 deaths and 146 injured. However, a similar case also happened in Hong Kong in 2004, yet some 1200 people were evacuated safely in less than 4 minutes, benefited from efficient emergency management and timely



actions. Therefore, an imperious demand for understanding the causal connections within all kinds of emergency has become indispensable in the daily operations of URTS. Based on such understandings, it is furthermore of extreme importance to establish an emergency management system for URTS to prevent personal injury, economic losses, cascading damages, etc. More precisely, it is urgently needed to have a management system for effective passenger evacuation in one station while the corresponding state propagation can be controlled among neighboring stations.

Most existing emergency management plans are composed of empirical schemes in which subjective experience and judgment are included that made the plans unreliable or untested in unexpected situations. Taking into consideration of practical difficulties and economic cost, however, it is impossible to carry out emergency drills too frequently. With the purpose of developing progressive scientific control and management for URTS, Wang [1] and Ning *et al.* [2, 3] proposed an ACP-based (Artificial system, Computational experiment, Parallel execution) control and management methodology for URTS using a parallel system and performed computational experiments based on artificial systems, which generates a promising orientation to provide virtual drill scenes inexpensively. Based on the same methodology, Dong *et al.* [4] studied the urban rail emergency response based on pedestrian dynamics and established an urban rail-transit emergency response system (URTERS).

Traditional research on the emergency response of URTS mainly focuses on emergency handling and management, resource assignment and scheduling. Compared with such traditional emergency management approaches, the ACP-based method takes into account the impacts of human, economic and environmental factors, and is able to capture the dynamic and stochastic nature of emergency response and management. Regarding the pedestrian dynamics, Helbing *et al.* [5] simulated the dynamical features of collective human behaviors with panic, removing the assumption that people are completely rational and identical [6, 7] which is far from the reality. In comparison, the ACP-based method can easily incorporate human behavior and dynamic analysis into the system. Therefore, this paper will incorporate the ACP-based method into the system for analyzing and handling pedestrian dynamics and human behavior in emergency situations, emergency situation evolution among the stations involved, and the coordination mechanism of these two issues. The susceptible-infected-recovered (SIR) model [8], proposed by Kermack and McKendrick in 1927, originally used for epidemic transmission research (see [9], for example), will be adopted in this paper to model the emergency state propagation among subway stations.

The rest of the paper is organized as follows. Section 2 describes the general idea of emergency management of URTS using parallel control, with more detailed design and realization procedures presented in Section 3. Conclusions including discussion on future work are given in Section 4.



## 2 Emergency management of URTS using parallel control

Emergency management of URTS using parallel control can be implemented by the following three procedures initiated in our previous work:

- i*): Artificial system (A): establish an agent-based artificial emergency system (A-AES) that is “equivalent” to the actual system with emergency situation;
- ii*): Computational experiment (C): design and carry out computational experiments on A-AES to recur, simulate, and forecast the tendency of system emergency response;
- iii*): Parallel execution (P): parallel execution and receding optimization between A-AES and actual URTS.

The structure of ACP-based emergency management for URTS is given in Figure 1.

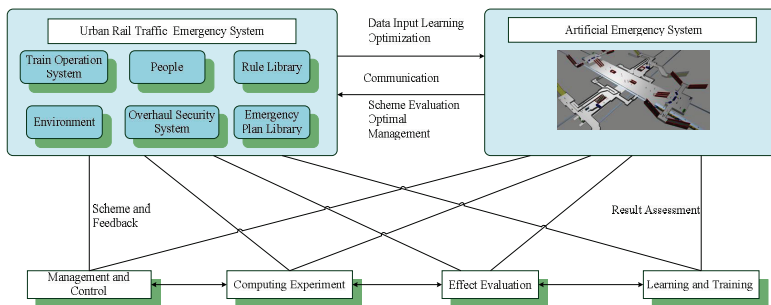


Figure 1: Architecture of ACP-based emergency management of URTS.

## 3 System design and implementation

As mentioned before, we first establish an agent-based artificial emergency system (A-AES) based on 3 levels of the whole rail transit network, including, *i*): transit hub in the rail transit network; *ii*): railway line in the rail transit network; *iii*): the whole railway net [4]. A visualized structure of A-AES is given in Figure 2.

In the A-AES, pedestrian behavior is generated using individual agent linked together by pedestrian dynamics, emergency state propagation among stations is described by susceptible-infected-removed (SIR) model, which will be discussed below. Thus, the whole A-AES from the bottom up has been established, which should be able to reproduce, simulate, and forecast the behavior of an URTS. Based on the A-AES, computational experiments are carried out in the condition that the system is under emergency situation. Using information fusion techniques, all the experimental data are captured and stored for the sake of emergency coping mechanism and benignant interaction between A-AES and actual URT emergency system. The following subsections present two key components of the system, namely the transit hub and the railway network.

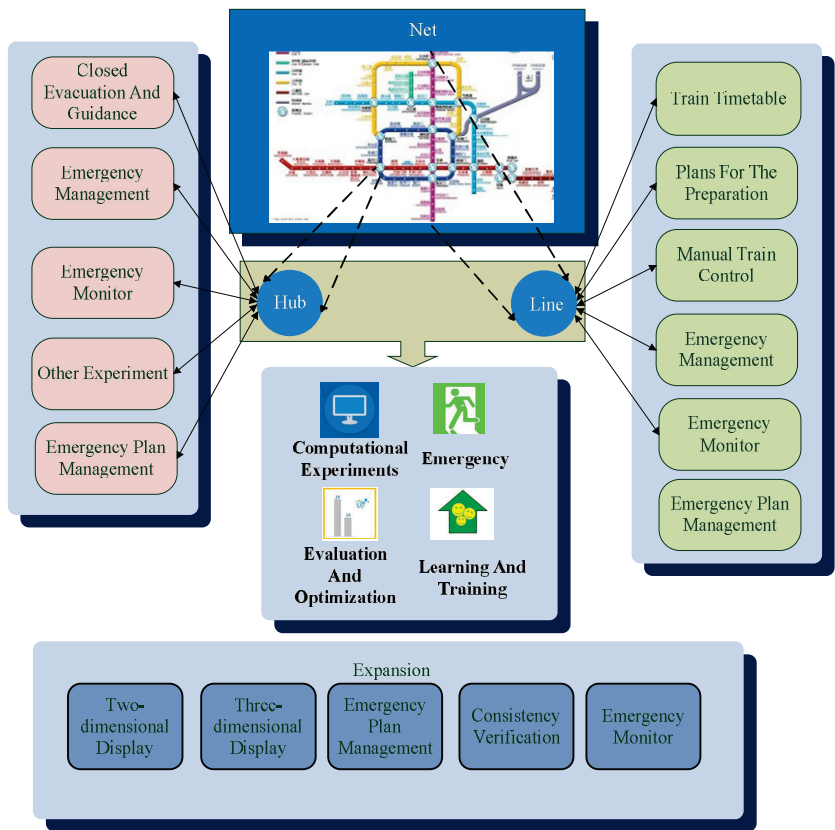


Figure 2: Framework of the URTERS.

### 3.1 Transit hub

A transit hub artificial system is modeled on a typical transit hub of the Beijing metro network. Main units in the transit hub, including train, platform, halls, escalators and others, are modeled using agent-based approaches. Passengers' behaviors are established adopting social force models [10]. The inner logic structure diagram of A-AES is showed in Figure 3, including generating passengers, route selecting, walking route, walking area, changing ground, and passenger sink.

The computational experiments of evacuation in case of terrorist attack, a severe emergency event, are executed to analyze the evacuation time and killed persons in different bombing position, as showed in Figure 4. The four line in the left-up diagram means the real-time total passenger number in the transit hub, the real-time passenger number in transfer hall, platform for Line 2 and Line 4, respectively.



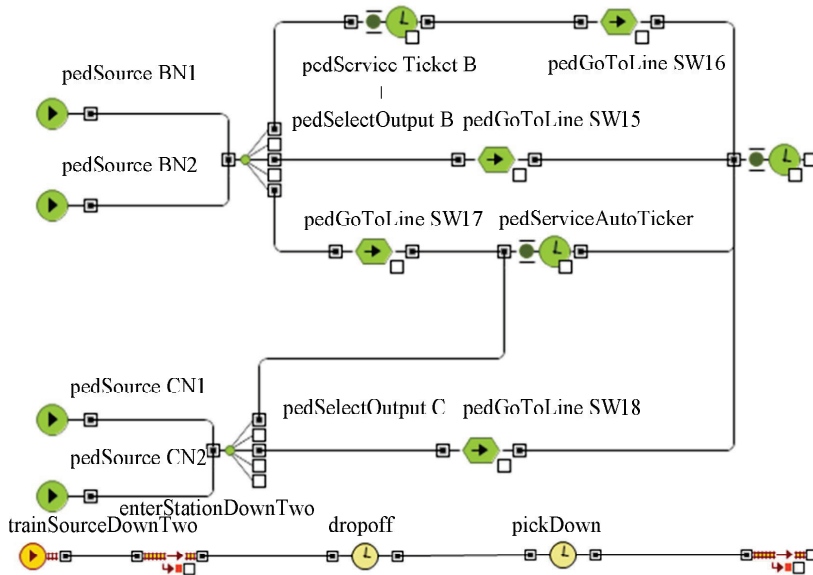


Figure 3: Inner logic structure diagram of A-AES.

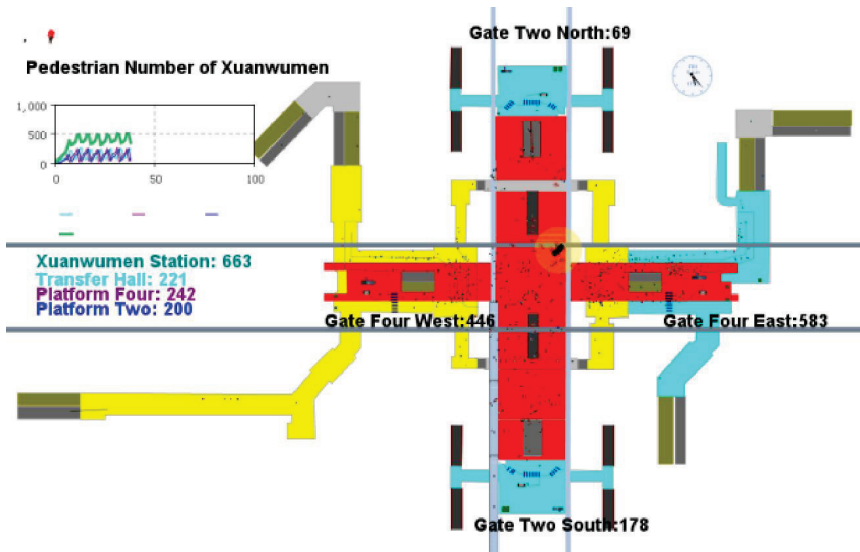


Figure 4: An emergency terrorist bombing happened in a station (indicated by the yellow cycle).

### 3.2 Railway network

The impact analysis of passenger flow under emergency in the urban rail network is studied, where the passenger flow is occurred in one transit hub. The number

of subway stations affected by the passenger flow is calculated. The SIR model, widely used in the disease propagation research, is adopted, where the original station occurring emergency passenger flow can be regarded as the source of infection. After discretization, SIR model can be written as:

$$\begin{cases} S_{t+1} = S_t - \beta I_t S_t \\ I_{t+1} = I_t + \beta I_t S_t - \eta I_t \\ R_{t+1} = R_t + \eta I_t \end{cases} \quad (1)$$

where  $S_t$ ,  $I_t$ ,  $R_t$ ,  $\beta$ ,  $\eta$  denote respectively the number of subway stations that will emerge with sudden passenger flow, the number of subway stations that are experiencing sudden passenger flow, the number of subway stations that will return to normal after sudden passenger flow, the propagation rate of sudden passenger flow, and the degradation rate of sudden passenger flow.

The expected value of number of subway stations that will emerge sudden passenger flow is given as:

$$E(-S) = k\beta - \eta \quad (2)$$

By incorporating equation (2) to (1), we get the cascading propagation model as:

$$I_{t+1} = I_t + (k\beta - \eta)I_t - \eta I_t. \quad (3)$$

The propagation and degradation rate of sudden passenger flow can be quantifiably expressed as:

$$\beta = \frac{v_{in} + v_{off}}{P_c - C_p} \quad (4)$$

$$\eta = \frac{v_{out} + v_{on}}{P_c - C_p} \quad (5)$$

where  $V_{in}$ ,  $V_{off}$ ,  $P_c$ ,  $C_p$ ,  $V_{out}$ ,  $V_{on}$  denote passenger flow entering speed, getting off speed, current passenger flow, station capacity, leaving speed, getting on speed, respectively.

i). To test the impact of different strategies with different scale emerging passenger flow, two series of computational experiments are carried out with parameters  $I_0 = 1$ ,  $C_p = 10000$ ,  $k = 5$ ,  $a = 20\%$  and the following three value sets:

a). small-scale:  $P_c = 12000$ ,  $v_{in} = 280$ ,  $v_{out} = 280$ ,  $v_{on} = 110$ ,  $v_{off} = 250$ ;

b). medi-scale:  $P_c = 13000$ ,  $v_{in} = 350$ ,  $v_{out} = 150$ ,  $v_{on} = 80$ ,  $v_{off} = 280$ ;

c). large-scale:  $P_c = 16000$ ,  $v_{in} = 500$ ,  $v_{out} = 100$ ,  $v_{on} = 50$ ,  $v_{off} = 360$ .

The results are shown in Figure 5, where Figure 5(a) shows the increasing rates of subway stations under condition of small-scale, medium-scale and large-scale emerging passenger flow, Figure 5(b) represents the sum of subway stations affected by emerging passenger flow.

ii). To test the impact of passengers limiting & degree on initial station with the same parameters as large-scale emerging passenger flow, two series of computational experiments are carried out by setting the passengers limiting: 20%,

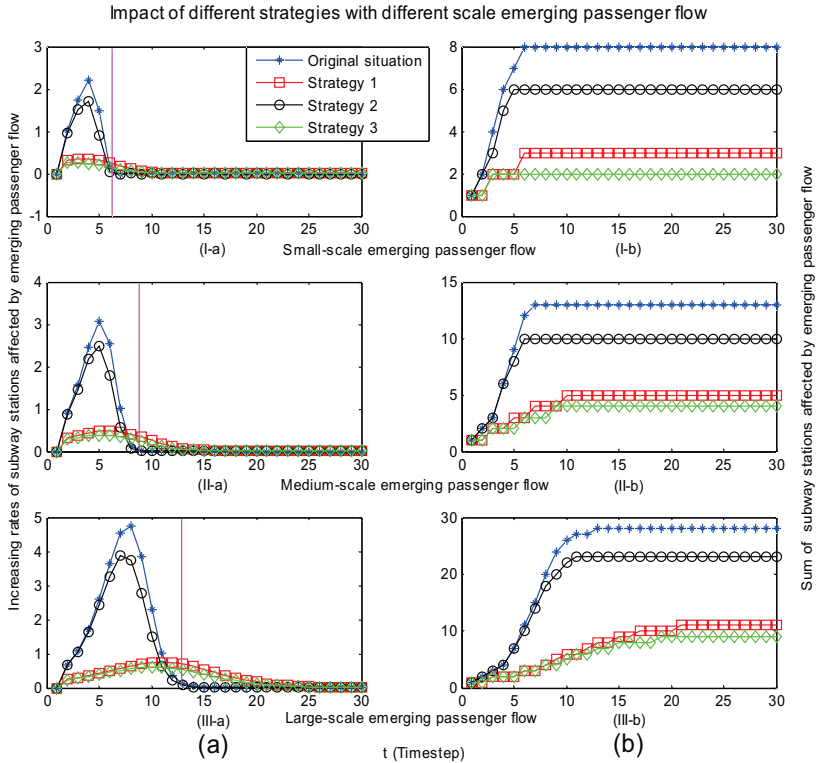


Figure 5: (a) Increasing rates of subway stations under condition of small-scale, medium-scale and large-scale emerging passenger flow, respectively. (b) Sum of subway stations affected by emerging passenger flow.

50%, 80% and degree on initial station 3, 4, 5, 6, corresponding results can be found in Figure 6(a) and 6(b), respectively.

## 4 Conclusions and future work

Emergency management of urban rail transit system using parallel control is proposed based on three levels, namely, transit hub, line and subway network. Computational experiments of emergency events are executed in the transit hub and subway network, where the propagation and impacts can be calculated based on the designed system. In our future work, parallel execution and training system will be studied, where parallel execution will realize the emergency response interaction between A-AES and actual system, and response abilities of the URTS employees will be improved by training in the A-AES. Our ultimate goal is to fully connect the A-AES and actual URTS in emergency situation in a fully interactive mode, which will be a revolution in URTS emergency management and control.



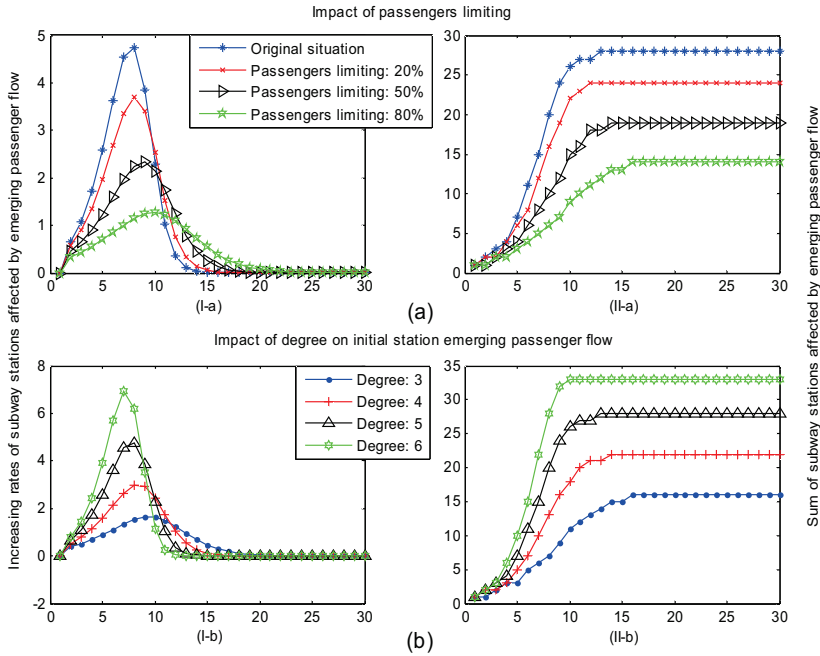


Figure 6: (a) Impact of passengers limiting by 20%, 50%, 80% (b) Limiting degree on initial station by 3, 4, 5, 6.

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