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Modeling and Simulation for Distribution Service Network of Comprehensive Passenger Transport Hub

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Abstract- Research in this paper is focused on the modeling and simulation for distribution service network (DSN) of comprehensive passenger transport hub (CPTH). Firstly, based on the theory and method of complex network, the conception of DSN is proposed. Secondly, the model of DSN is build which consists of distribution entity topology network, distribution transport function network and distribution service function network. And then, Anylogic software is adopted to simulate the distribution process of passenger flow in CPTH by comparative analyzing the simulation performances among pedestrian simulation software. Finally, the transfer hall of Beijing South subway station is selected for case study, the results show that this method has strong readability and operability. Findings of this research are of practical significance in performance evaluation of passenger flow distribution.

Keywords- *Comprehensive passenger transport hub, Distribution service network, Simulation model by Anylogic, Performance evaluation.*

I. INTRODUCTION

In recent years, the crucial issues of comprehensive passenger transport hub (CPTH) during the operating period mainly show serious passenger flow congestion and the low levels of distribution efficiency. Therefore, in order to satisfy passenger flow traffic demand and achieve high efficiency for passenger transfer, research on the modeling and simulation for distribution service network (DSN) of comprehensive passenger transport hub (CPTH) are of great significance.

Domestic and foreign scholars had an abundant of research on service network, hub transfer efficiency and passenger behavior analysis. As a new type composite cross subject, service network has been got widely attention and development. With the application of social relations network idea, Wang Hui [1] defined service network as a directed graph, divided service network into abstract layer and concrete layer, designed the ontology of service network, and described the semantic relationship between service and servicelink. Especially in the field of computer science and technology, taking the modern satellite communication network for example, Boris S. Verkhovsky [2] designed service network topology by using dynamic programming method. Chen Shizhan [3] defined service network as a three-dimensional hinged network which included dependence, relationship, attribute and capacity. By Applying complex network theory and method, E Haihong [4] proved that service network has a "small world" and "scale-free" characteristics, and set up a topology design method. Meanwhile, Service network has achieved in-depth research and application in the transport field. Xu Wangtu [5] defined the concept of comprehensive freight service network, and set up the calculation model and algorithm of service network transport capacity. Based on train operation plan, Hu Bisong [6] researched the reasonable path search technology, constructed passenger service network and developed the train operation plan service network management system.

On the other hand, in the field of hub transfer efficiency and passenger behavior analysis, passenger individual behavior model was set up by Gipps [7] for the first time, they supposed that pedestrian movement obeyed the law of short circuit, and put forward a simple route choice model. Helbing [8] illustrated the complex characteristics of pedestrian traffic flow, and built social force model. Lee [9] put forward an optimization method of the relaxation time to improve the transfer efficiency among each modes of transportation. Daamen [10,11] summed up that passengers crowded degree of hub interlayer facility as the key factor directly affected passenger route choice behavior by the research on the relationship between interlayer facility design layout and passenger pathfinding. By using simulation, Seti. J.R. [12] and Lin.Y-D. [13] analyzed passenger flow characteristics inside of the hub, and identified passenger flow distribution bottleneck.

From the previous literature review, it can be found that kinds of researches were widely used to simulate the passenger flow distribution, and each method had its own advantages and limitations in different applications. However, there were few research works related with the modeling and simulation for distribution service network of comprehensive passenger transport hub. Therefore, the objective of this paper is to set up the model of distribution service network and to simulate the distribution process of passenger flow in CPTH. More specifically, the three sub-objectives are as follows:

(i) To build the conception and model of DSN based on the theory and method of complex network.

(ii) To set up the simulation model of passenger flow distribution by Anylogic based on comparative analyze the simulation performances among pedestrian simulation software and consider passenger flow characteristics in the CPTH.

(iii) To select the transfer hall of Beijing South subway station for case study, then evaluate the model performance.

II. MODEL OF DISTRIBUTION SERVICE NETWORK

A. Passenger Flow Distribution Process

In CPTH, passenger flow distribution refers to the whole process of transfer service among various modes of transportation, the objective is accomplishing the different travel demands. What's more, passenger flow distribution is a cohort effect formed from the interaction between passenger transfer behavior and the internal environment of hub. Schematic of passenger flow distribution process is shown in Fig. 1.

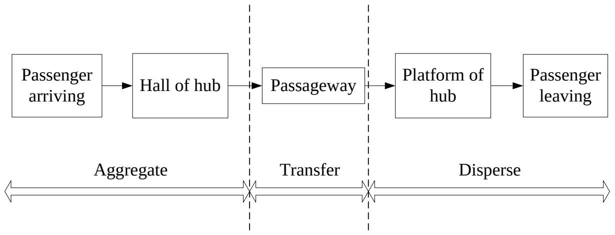

Figure 1. Schematic of passenger flow distribution process

What's more, based on the passenger flow direction, passenger flow line can be divided into three types, including passenger flow input line, passenger flow transfer line and passenger flow output line, as shown in the following Figures.

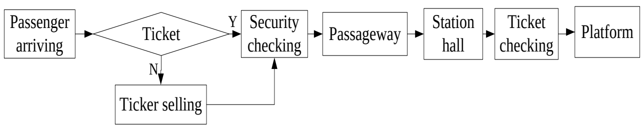

Figure 2. Schematic of passenger flow input line

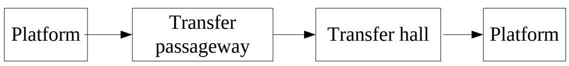

Figure 3. Schematic of passenger flow transfer line

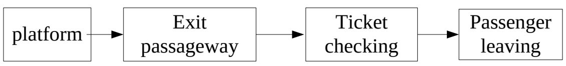

Figure 4. Schematic of passenger flow output line

Based on the above figures, the conception of distribution service network has the following characteristics analyzed by the theory and method of complex network, which are shown in the following table.

TABLE I. CONCEPTION OF DSN IN CPTH

Item	Detail
network elements	entity topology network, transport function network and service function network
network property	directed flow network
service object	passenger flow in CPTH
service process	the whole process of passenger flow distribution in CPTH
network objective	passenger flow traffic demand in CPTH

B. Model of Distribution Service Network

The Distribution Service Network (DSN) of Comprehensive Passenger Transport Hub (CPTH) is a function system for passenger flow transfer contains the space-time characteristics, which consists of distribution infrastructure, passenger organization process and guide service facility. Inside of CPTH, DSN is built based on the infrastructure network, supported by the information resources network, and operates according to the passenger transport organization modes.

The DSN could be divided into three sub-network in accordance with its composition, which are distribution entity topology network, distribution transport function network and distribution service function network. By means of the dynamic collaboration between passenger subjective behavior and distribution objective environment, the efficient distribution for large-scale passenger flow is achieved. Schematic framework of DSN is shown in Fig. 5.

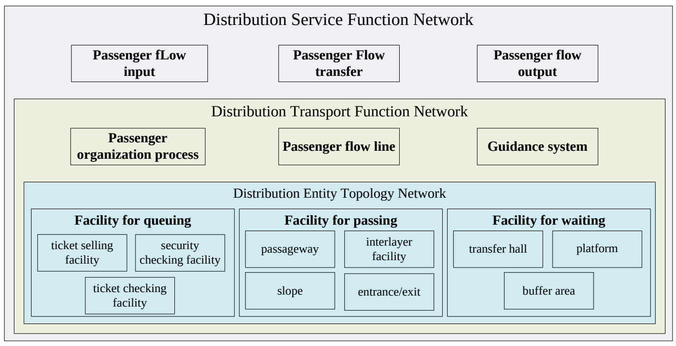

Figure 5. Schematic framework of DSN

1) Distribution Entity Topology Network

In general, passenger cognition to the spatial structure relations among facilities in CPTH is shown as the network topology. Therefore, based on the node and adjacency of network, distribution entity topology network is built to describe the hub environment, which is shown in the following.

$$G_T = (N_T, A_T) \tag{1}$$

$$N_T = (i, j, p, s) \tag{2}$$

$$A_T = (o, d, c, l) \tag{3}$$

Where, G_T refers to distribution entity topology network; N_T refers to the set of facility node; A_T refers to the set of facility adjacency; i refers to the node number; j refers to the node type; P refers to the physical property of node, namely a set about the basic parameters of the facilities such as length, width, height, area and so on; S refers to the spatial property; o refers to the origin of facility adjacency; d refers to the destination of facility adjacency; l refers to the relation of facility adjacency.

2) Distribution Transport Function Network

Based on distribution entity topology network, distribution transport function network is built by superposing passenger organization process, passenger flow line and guidance system. What's more, facility function parameters are assigned to the node and adjacency of facility, which is shown in the following.

$$G_F = (N_F, A_F, W, R, D) \tag{4}$$

$$N_F = (i^{'}, j^{'}, p^{'}, s^{'}, q_{i^{'}}) \tag{5}$$

$$A_F = (o^{'}, d^{'}, c^{'}, l^{'}, q_{(od)^{'}}) \tag{6}$$

$$W = g_1(N_F, A_F) \tag{7}$$

$$R = g_2(N_F, A_F) \tag{8}$$

$$D = (s_d, r_d) \tag{9}$$

Where, G_F refers to distribution transport function network; N_F refers to the set of function facility node; A_F refers to the set of function facility adjacency; W refers to passenger organization process; R refers to passenger flow line; D refers to guidance system; $i^{'}$, $j^{'}$, $p^{'}$, $s^{'}$, $o^{'}$, $d^{'}$ and $l^{'}$ are as same as i, j, P, S, o, d and l; $q_{i^{'}}$ refers to functional property to $i^{'}$, which includes facility operation parameters; $c^{'}$ refers to the set of the connected function facilities; $q_{(od)^{'}}$ refers to functional property to $(od)^{'}$, which includes adjacency operation parameters; g_1 and g_2 refer to functions between N_F and A_F; s_d refers to the spatial property of guidance system; r_d refers to the set of passenger flow lines in guidance system.

3) Distribution Service Function Network

In this paper, distribution service function network refers to the DSN, which is built by inputting the dynamic passenger flow into distribution transport function network. It is a functional network for the passenger flow distribution in the hub, which is shown in the following.

$$G_S = (N_F, A_F, W, R, D, Q_S) \tag{10}$$

$$N_F = (i^{'}, j^{'}, p^{'}, s^{'}, q_{i^{'}}) \tag{11}$$

$$A_F = (o^{'}, d^{'}, c^{'}, l^{'}, q_{(od)^{'}}) \tag{12}$$

$$W = g_1(N_F, A_F) \tag{13}$$

$$R = g_2(N_F, A_F) \tag{14}$$

$$D = (s_d, r_d) \tag{15}$$

$$Q_S = (m, \rho, v, f, L, n) \tag{16}$$

Where, G_S refers to distribution service function network; Q_S refers to the set of passenger flow parameter; m refers to the distribution of passenger flow; ρ refers to the density of passenger flow; v refers to the speed of passenger flow; f refers to the passenger flow volume; L refers to the queuing length of passenger flow; n refers to the queuing number of passenger flow.

C. Model Case

In this research, the transfer hall of Beijing south subway station is selected as an example for model of DSN, which is located in the first floor underground of Beijing South Railway Station. Passenger can transfer among the different traffic modes such as high-speed railway, urban rail transit and urban public bus. The structure schematic of Beijing South Subway Station is shown in Fig. 6.

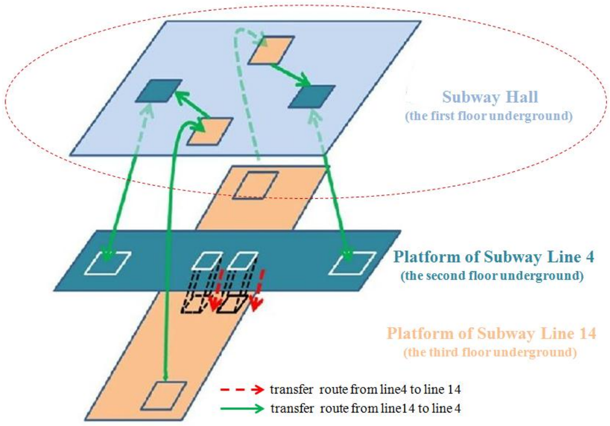

Figure 6. Schematic of Beijing South Subway Station

Based on the practical investigation, the model of subway transfer hall is built in the following.

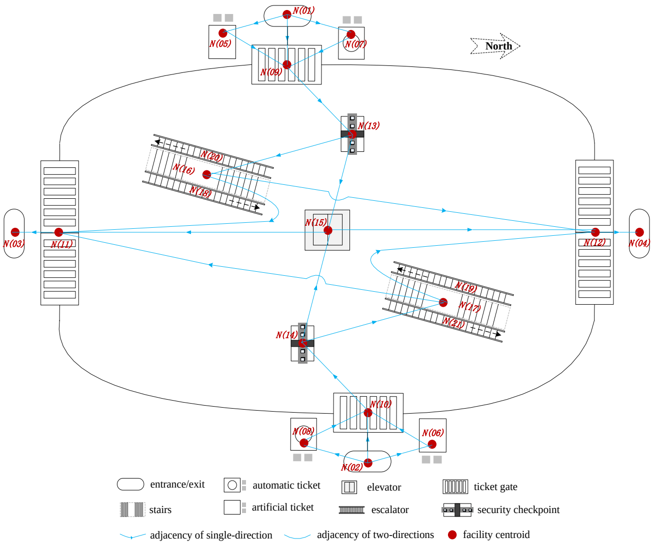

Figure 7. Model of subway transfer hall of Beijing South Subway Station

TABLE II. PARAMETERS OF FACILITY

Facility Node No.	Facility name	Facility Node No.	Facility name
01	west entrance	12	ticket gate of north exit
02	east entrance	13	west security checkpoint
03	south exit	14	east security checkpoint
04	north exit	15	elevator
05	artificial ticket office of west entrance	16	west stairs
06	artificial ticket office of east entrance	17	east stairs
07	automatic ticket of west entrance	18	west uplink escalator
08	automatic ticket of east entrance	19	east uplink escalator
09	ticket gate of west entrance	20	west downlink escalator
10	ticket gate of east entrance	21	east downlink escalator
11	ticket gate of south exit		

III. SIMULATION DESIGN OF DISTRIBUTION SERVICE NETWORK

Anylogic software is a professional simulation environment for virtual prototyping based on UML-RT, Java and differential equation. It is efficiently used for the simulation of complex systems which contain discrete system, continuous system and hybrid system. So far, Anylogic is widely applied to the dynamic simulation in traffic and transportation. In this paper, pedestrian library in Anylogic is adopted to set up the simulation environment of passenger flow distribution of subway transfer hall. Simulation process of Anylogic is shown in Fig. 8.

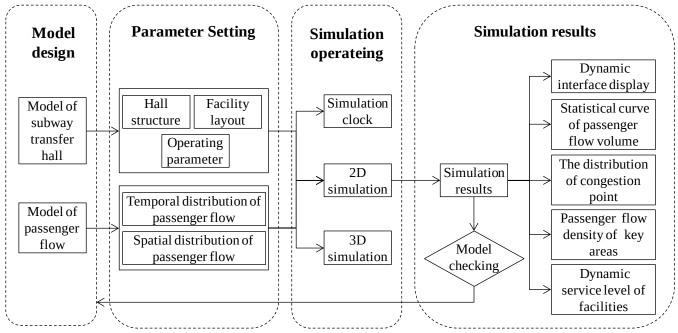

Figure 8. Simulation process of Anylogic

A. *Simulation Model of Subway Transfer Hall*

Based on the parameters of hall structure and facility layout, simulation model of subway transfer hall is built by using Anylogic, which is shown in Fig. 9.

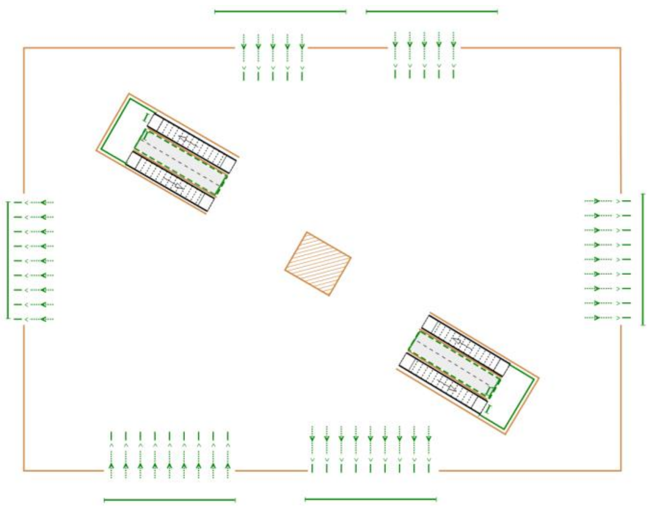

Figure 9. Simulation model of subway transfer hall by Anylogic

B. *Simulation Model of Passenger Flow*

The pedestrian library is used to set up passenger flow model in the physical space and accurately simulate the traffic behavior of passenger which core algorithm is social force model. And in general, the walking speed value of passenger flow is set as 1.0-1.5m/s. In this paper, the pedestrian library is adopted to set up the simulation model of passenger flow distribution in subway transfer hall, which is shown in Fig. 10.

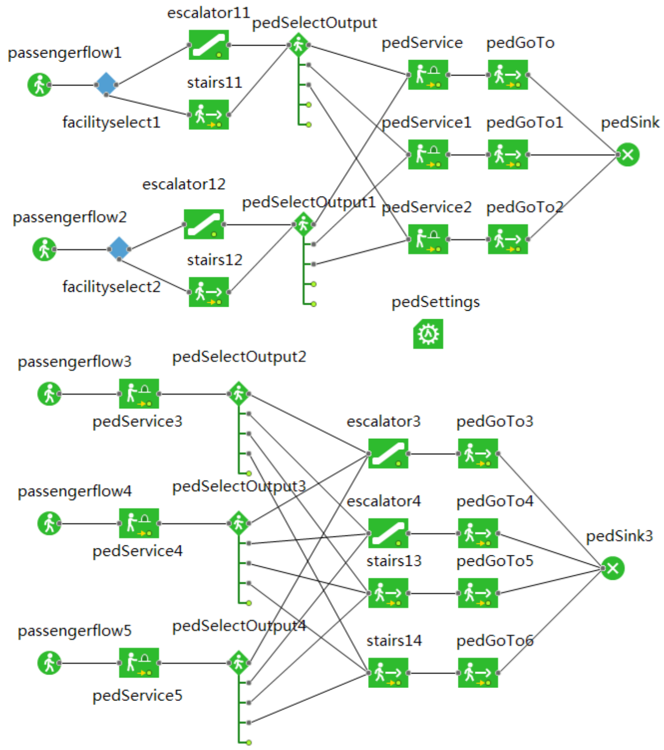

Figure 10. Simulation model of passenger flow distribution in subway transfer hall by Anylogic

IV. CASE STUDY AND RESULTS ANALYSIS

In this paper, the practical investigation data of Beijing South Subway Station in the following table is adopted for case study.

TABLE III. PRACTICAL INVESTIGATION DATA OF SUBWAY TRANSFER HALL

Item	Detail
location of practical investigation	the subway transfer hall in Beijing South Subway Station (the first floor underground of Beijing South Railway Station)
dates of practical investigation	July 11-13, 2016
peak hour of practical investigation	07:30-08:30
data contents of practical investigation	facilities data of subway transfer hall passenger flow data

Based on the simulation models for case study and the practical investigation data of subway transfer hall, the simulation results are shown in the following.

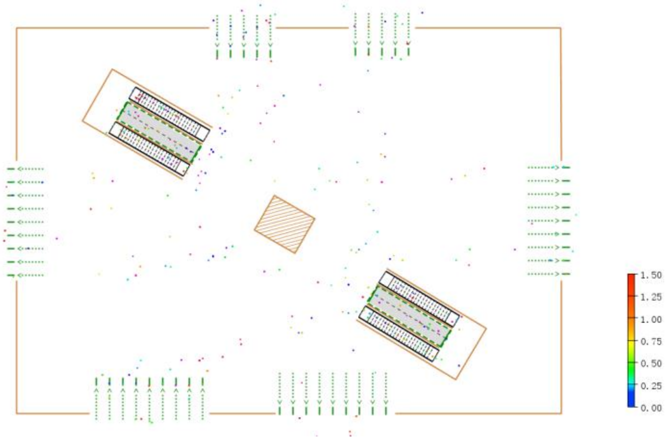

Figure 11. Schematic diagram of simulation interface display without density map showing

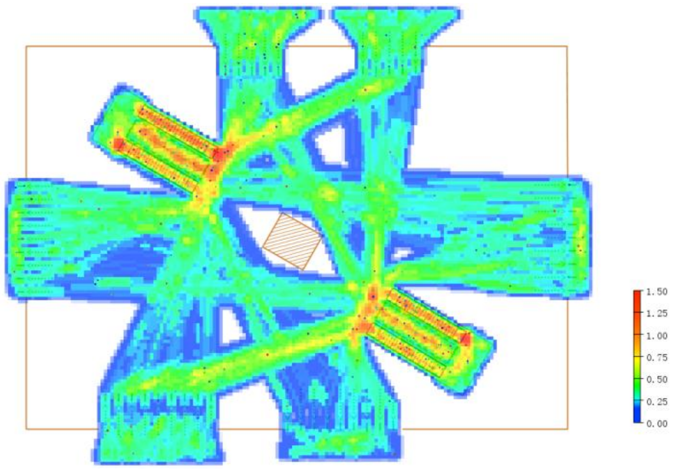

Figure 12. Schematic diagram of simulation interface display with density map showing

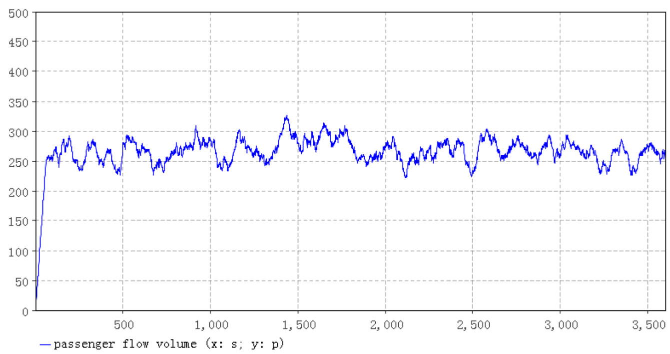

Figure 13. passenger flow volume of subway transfer hall in the peak hour

From the above figure, it is concluded that the maximum volume of passenger flow of subway transfer hall in the peak hour is 332. The results show that the service level of subway transfer hall in the peak hour is high, which is consistent with the reality scene completely.

V. CONCLUSION

In this paper, the conception and model of DSN is built based on the theory and method of complex network, moreover, the transfer hall of Beijing south subway station is selected as an example for model. And then, simulation process of Anylogic is proposed and the simulation model of passenger flow distribution is set up by Anylogic, which includes simulation model of subway transfer hall and passenger flow. Based on the practical investigation of subway transfer hall in the peak hour, case results show that the model and simulation of DNS have a good performance. Findings of this research are of practical significance in performance evaluation of passenger flow distribution.

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