

# A Modeling Method for Distribution Service Network of Comprehensive Passenger Transport Hub

Gao Long<sup>1,2,3</sup>, Jia Limin<sup>2,3,\*</sup>, Qin Yong<sup>1,2,3</sup> and Li Qian<sup>4</sup>

<sup>1</sup>School of Traffic and Transportation, Beijing Jiaotong University, Beijing, 100044, P.R. China

<sup>2</sup>State Key Laboratory of Rail Traffic Control and Safety, Beijing Jiaotong University, Beijing, 100044, P.R. China

<sup>3</sup>Beijing Research Center of Urban Traffic Information Sensing and Service Technologies, Beijing Jiaotong University, Beijing, 100044, P.R. China

<sup>4</sup>Henan Provincial Communications Planning Survey and Design Institute Limited Company, Zhengzhou, 450000, P.R. China

**Abstract:** Aim at the modeling problem for distribution service network (DSN) of comprehensive passenger transport hub (CPTH), the three-phrase modeling method for designing DSN is proposed, which consists of factor analysis, factor description and network integration. Based on the analysis to passenger transport behavior demand, the conception of DSN is defined for the first time. The DSN is a network system possesses of spatial-temporal feature and distribution function, which is coupled by three parts such as internal passenger flow distribution infrastructure, passenger organization process and guidance service facilities. Using the theory and method of system engineering to study on the properties of three layers, the property description model for each layer is established. By integrating space attribute data and service attribute data of each layer, the three-phrase modeling method and operation process are put forward, therewith, the model of DSN is built, ultimately realizes the digital description of DSN. The case shows that this method has strong readability and operability.

**Keywords:** Comprehensive passenger transport hub, distribution service network, the three-phrase modeling method.

## 1. INTRODUCTION

Passenger flow distribution function inside of the Comprehensive Passenger Transport Hub (CPTH) is the core for CPTH planning, design, construction and operation management. The inside passenger distribution environment has gradually developed into a function system for passenger flow distribution service. Therefore, the distribution efficiency directly influences the overall network efficiency. With this, the Distribution Service Network (DSN) emerges, which consists of distribution infrastructure, passenger organization process and guide service facility. Carrier of the distribution function is the infrastructure network satisfied multiple organizational patterns. As the distribution service object, passenger transfer behaviors could be regarded as a set of transfer activity demands. In order to satisfy passenger trip demand and achieve high efficiency for passenger transfer, study on the DSN analysis and modeling of CPTH is of great significance.

Scholars at home and abroad had in-depth academic research on the analysis and modeling of service network, hub transfer efficiency and passenger behavior analysis. In the

study of service network, as a new type composite cross discipline, service network has been got widely attention and development. Especially in the field of computer science and technology, taking the modern satellite communication network for example, Boris S. Verkhovsky [1] designed service network topology by using dynamic programming method. With the application of social relations network idea, Wang Hui [2] 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. 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. What's more, Service network has achieved in-depth research and application in the field of transportation. Based on train operation plan, Hu Bisong [5] researched the reasonable path search technology, constructed passenger service network and developed the train operation plan service network management system. Shen Rui [6] put forward service network design theory and method of railway express transport, specifically set up service network design theory and algorithm in the field of the special train transport and packet transport. Xu Wangtu [7] defined the concept of comprehensive freight service network, and set

\*Address correspondence to this author at the State Key Laboratory of Rail Traffic Control and Safety, Beijing Jiaotong University, Beijing, 100044, P.R. China; Tel: +8615201328873; E-mail: 11114234@bjtu.edu.cn.

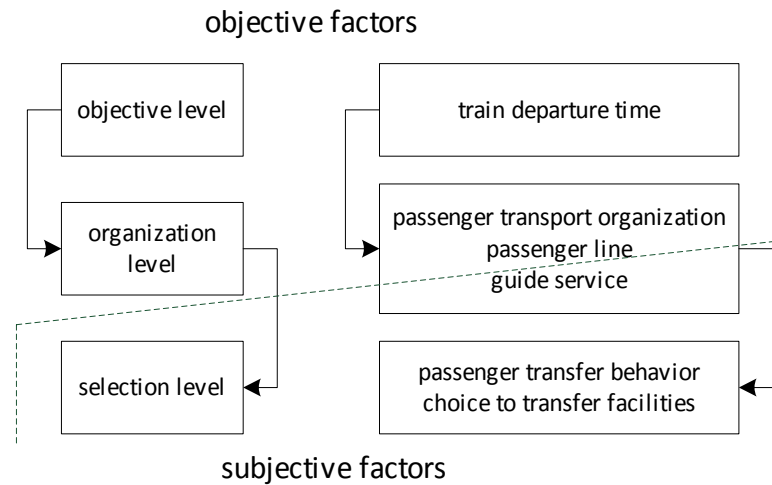


Fig. (1). The levels of passenger transfer activities.

up the calculation model and algorithm of service network transport capacity.

On the other hand, that is in the field of hub transfer efficiency and passenger behavior analysis, in order to improve the transfer efficiency among each modes of transportation, Lee [8] put forward an optimization method of the relaxation time. Non-uniform DEA evaluation model was introduced for analyzing the service efficiency of urban passenger transfer hub effectively [9]. By using simulation, Seti. J.R. [10] and Lin.Y-D. [11] analyzed passenger flow characteristics inside of the hub, and identified passenger flow distribution bottleneck. What's more, corresponding measures were adopted to improve passenger transfer efficiency. Passenger individual behavior model was set up by Gipps [12] for the first time, they supposed that pedestrian movement obeyed the law of short circuit, and put forward a simple route choice model. In addition, Helbing [13] illustrated the complex characteristics of pedestrian traffic flow, and built social force model. Daamen [14, 15] 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. Jia Hongfei [16] built a system analysis method of interlayer facility ability adaptability, and achieved the parameters selection of interlayer facility configuration scheme with the help of simulation method.

In this paper, based on the analysis to passenger transfer behavior demand, the conception of DSN is defined for the first time. Using the theory and method of system engineering to study on the properties of three layers, the property description model for each layer is established. By integrating space attribute data and service attribute data of each layer, the three-phrase method and operation process are put forward, therewith, the model of DSN is built, ultimately realizes the digital description of DSN. The case shows that this method has strong readability and operability.

## 2. DISTRIBUTION SERVICE NETWORK

### 2.1. Passenger Transfer Behavior

Passenger traffic transfer 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. In this paper, according to the train of thought which is stratifying passenger travel behavior, and combining with the characteristics of passenger transfer behavior, passenger transfer activities are divided into three levels, they are objective level, organization level and selection level. As shown in Fig. (1), the dotted line expresses a partition to subjective and objective factors which influences passenger transfer behavior. The objective factors locate above the dotted line, for example, the train departure time. Corresponding, the subjective factors locate below the dotted line, for example, the choice to transfer facilities.

### 2.2. The Conception 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. The first one is the distribution infrastructure network made up of hub fixed facilities; the second one is the distribution operation network consist of passenger transport organization modes and transfer lines; the third one is distribution information resources network

**Table 1. Passenger flow line and passenger organization process**

Passenger Flow Line	Passenger Organization Process
input line	pull in → ticket check → get on
output line	get off → ticket check → outbound
transfer line	get off → ticket check → (ticket) → ticket check → get on

includes various transportation resources and guide information resources. By means of the dynamic collaboration between passenger subjective behavior and distribution objective environment, the efficient distribution for large-scale passenger is achieved.

### 3. SYSTEM ANALYSIS OF DISTRIBUTION SERVICE NETWORK

#### 3.1. System Boundary

As a system, DSN system is an internal subsystem of CPTH system. It is very necessary to research and define the boundary of DSN system. In general, passenger distribution activities include passenger aggregation activity and evacuation activity. Specifically, entering into the hub could be accounted as aggregation, and leaving the hub could be accounted as evacuation.

Therefore, the boundary of DSN system could be defined by passenger choice to the different transportation modes. As follows, to walk, the system boundary is hub entrance; to public traffic, that is passenger access point; to private car and taxi, that is parking lot.

#### 3.2. System Characteristics

The DSN system should inherit the general features of CPTH system, meanwhile, has its own system characteristics.

##### 1. Complexity and Hierarchy

In order to realize the mutual adjustment among the various passenger transport modes, the layout and configuration of the passenger transport equipments should be given an overall consideration. Thus, the complexity of DSN is reflected. What's more, the hierarchy viewpoint of system could be regarded as a method to hierarchically analyze the complexity of system.

##### 2. Dynamic Continuity of Links Between Interiors and Exteriors

It is generally known that the exchange about material, energy and information between interiors and exteriors is continuous. The passenger flow intensities of DSN input and output present the typical space-time characteristics.

##### 3. Relative Independence and Harmonious Unity

In the system, each transport mode and equipment both has relatively independent function. On the other hand, as a whole, they are harmonious and unified to complete passenger transfer and distribution.

#### 4. Self-adaptive and Self-organization

As the external environment such as the transportation network and urban system changes, it is necessary to adjust the function of CPTH, meanwhile, the structure and characteristics of DSN should be adjusted or changed accordingly.

#### 5. Procedure and Periodicity

The procedure of passenger transfer in CPTH reflects the continuance of network service. In addition, the periodicity of capacity arrangement determines the regularity of passenger travel demand.

### 3.3. System Elements

The internal construction of system includes elements and structures. Firstly, the analysis of system elements and structures is proposed, and system elements are the basis of system structures. So, the DSN could be divided into three layers in accordance with its composition, they are infrastructure layer, passenger transport organization layer and guide service layer.

#### 1. Infrastructure Layer

In the CPTH, infrastructure refers to the set of physical facilities and equipments, which are served for passenger transfer and distribution. The various facilities constitute passenger distribution activity space.

#### 2. Passenger Transport Organization Layer

Passenger transport organization refers to the operation and organization modes for the passenger distribution by using the infrastructure. Passenger flow line is defined as the passenger travel path, which could be divided into input line, output line and transfer line. As we know, passenger flow line is restrained by passenger organization process. All kinds of passenger flow line and passenger organization process are shown in Table 1.

#### 3. Guide Service Layer

Guide service includes all kinds of guide information and facility, its function is directing passenger to transfer exactly.

#### 4. Contrastive Analysis of Three Layers

The contrastive analysis result of three layers is shown in Table 2.

### 3.4 System Structure

Based on the system theory, system structure refers to a set about components and links. Under the condition of the components are constant, the structure normally represents

Table 2. Contrastive analysis of three layers

	Infrastructure Layer	Passenger Organization Layer	Guide Service Layer
morphology	entity	logic	entity
action range	the whole network	partial mesh	single facility
directivity	no	yes	yes
connectivity	connected facilities	direction of flow	the next facility or process
capacity limitation	yes	no	no
elements	various traffic facilities and equipments	passenger organization process and passenger flow line	guide information and facilities

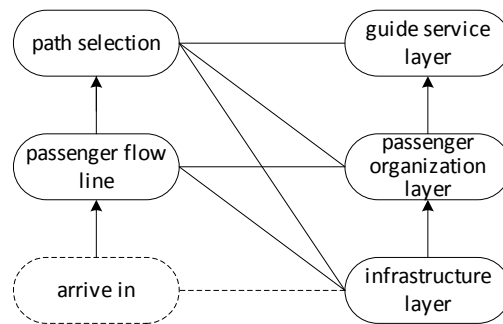


Fig. (2). System structure and connection.

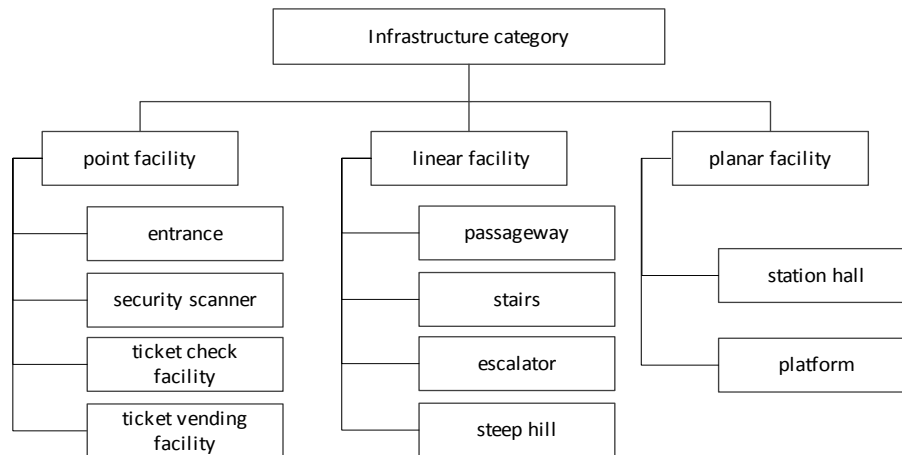


Fig. (3). Infrastructure category.

the links between any two components. As shown in Fig. (2), first, as the basic physics layer, the infrastructure layer is located at the bottom, which provides the fundamental environment for passenger distribution activities; second, passenger transport organization layer includes a set of organization processes, and according to this, passenger flow line is designed; third, the function of guide service layer is directing passenger path selection accurately.

#### 4. THE DESCRIPTION OF DISTRIBUTION SERVICE NETWORK

The rule to describe DSN is digitizing all kinds of property values about elements and structure. The property of

DSN mainly contains spatial property and service property. The spatial property includes physical property, spatial position and facilities links, etc. The service property includes service capability, operation condition and so on.

##### 4.1. Infrastructure Layer

###### 1. Infrastructure Category

The DSN of CPTH is a continuous space for passenger activities. In order to facilitate the research, in the basis of physical property, the infrastructure network is regarded as a topology network which includes point facility, linear facility and planar facility. As shown in Fig. (3).

###### 2. The Description of Infrastructure

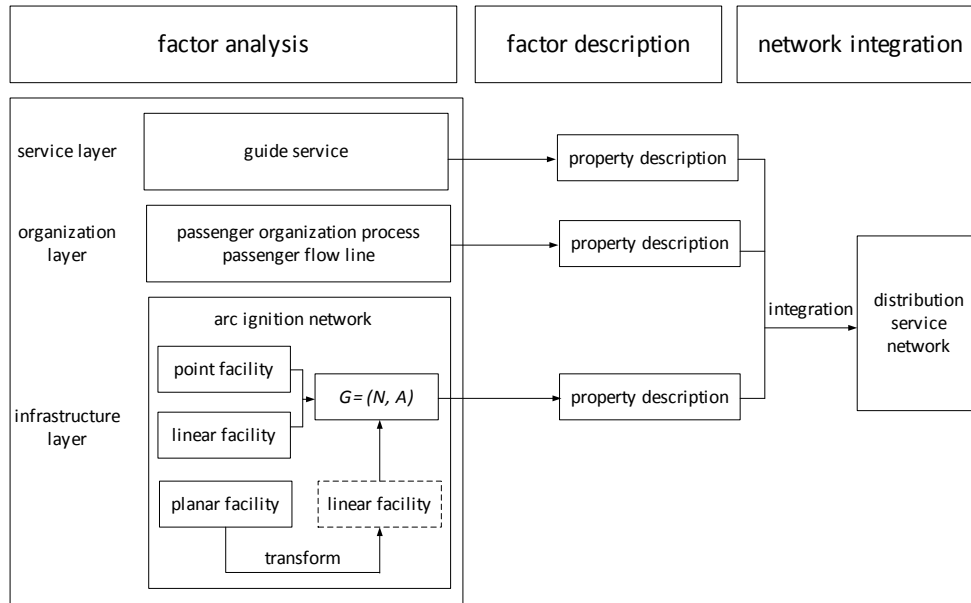


Fig. (4). The modeling method of DSN.

The infrastructure network is defined as an arc ignition network, and shown as  $G=(N,A)$ . The property contains physical property, spatial position, facilities links, service capability and operation condition. The formula is as follows:

$$F_i^j = \{P, S, C, Q, O\} \tag{1}$$

Where,  $i$  is facility number;  $j$  is the type of facility, 1 is point facility, 2 is linear facility, 3 is planar facility;  $P$  is physical property, namely a set about the basic parameters of the facilities such as length, width, height, area and so on;  $S$  is spatial property includes spatial position and floor belonged, what' more, interlayer facility is shown by (1,2);  $C$  is facility link, namely a set about connected facilities;  $Q$  is service capability, such as the number of passengers per unit time;  $O$  is operation condition for automation facility, such as running speed.

#### 4.2. Passenger Transport Organization Layer

This layer contains passenger organization process and passenger flow line. Passenger organization process refers to a set about business processes serving various passenger transfer activities. The formula is as follows:

$$W = \{w_1, w_2, \dots, w_n\} \tag{2}$$

Then, only according to the passenger flow line, passenger could be able to achieve the organization process in turn. Passenger flow line is shown as a set as follows:

$$R = \{f_1, f_2, \dots, f_m\} \tag{3}$$

There is a certain corresponding relation between  $W$  and  $R$ . The two collectively show the whole process of the passenger transfer behavior.

#### 4.3. Guide Service Layer

Guide service contains spatial position, direction and guide efficiency. The formula is as follows:

$$D = \{S, L, F\} \tag{4}$$

Where,  $S$  is spatial property including spatial position and floor belonged;  $L$  is a set about passenger flow line;  $F$  is a set about forward directions.

### 5. THE MODELING METHOD OF DISTRIBUTION SERVICE NETWORK

To the DSN, the purpose of modeling is describing passenger transfer environment and the range of activity. The modeling method of DSN includes three phases which are factor analysis, factor description and network integration. As shown in Fig. (4).

#### 5.1. Factor Analysis

Taking a railway station atrium area as an example, the information is as follows in Fig. (5) and Table 3.

Here, in order to matching with passenger transport organization and guide service, planar facility should be transformed into linear facility. Point facility, linear facility and planar facility are accordingly shown by dark spot, solid line and dotted line. The generated arc ignition network of infrastructure is as follows in Fig. (6).

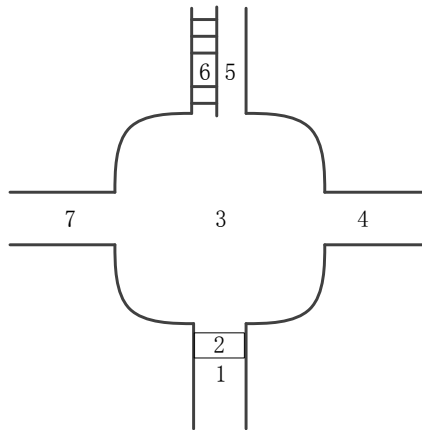


Fig. (5). The basic diagram of a railway station atrium area.

Table 3. Facility basic information

Facilities Number	Facility Name	Facility Category
1	pedestrian passageway	linear facility
2	security scanner	point facility
3	atrium	planar facility
4	pedestrian passageway	linear facility
5	escalator	linear facility
6	stairs	linear facility
7	pedestrian passageway	linear facility

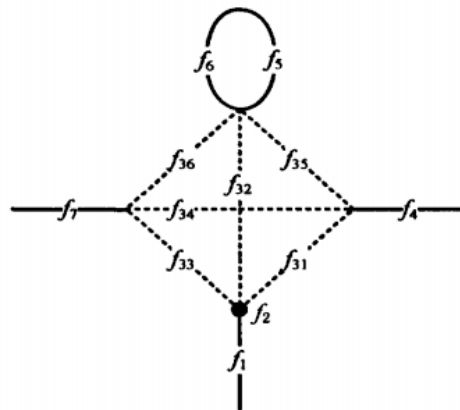


Fig. (6). The arc ignition network of infrastructure.

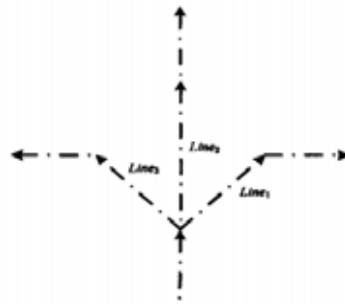


Fig. (7). The flow line network of passenger transport organization.

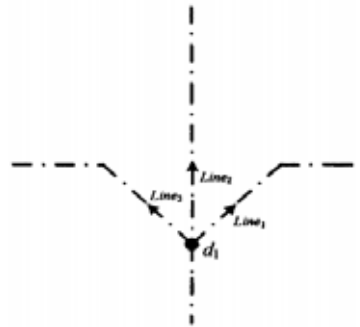


Fig. (8). The location of directional sign.

Table 4. The factor description of infrastructure.

Facilities Number	The Factor Description
1	$f_1^2 = \{(l_1, w_1), 1, 2, q_1\}$
2	$f_2^1 = \{1, (1, 3), q_2\}$
3	$f_{31}^2 = \{(l_{31}, +), 1, (2, 4), q_{31}\}$
	$f_{32}^2 = \{(l_{32}, +), 1, (2, 5, 6), q_{32}\}$
	$f_{33}^2 = \{(l_{33}, +), 1, (2, 7), q_{33}\}$
	$f_{34}^2 = \{(l_{34}, +), 1, (4, 7), q_{34}\}$
	$f_{35}^2 = \{(l_{35}, +), 1, (4, 5, 6), q_{35}\}$
	$f_{36}^2 = \{(l_{36}, +), 1, (5, 6, 7), q_{36}\}$
4	$f_4^2 = \{(l_4, w_4), 1, 3, q_4\}$
5	$f_5^2 = \{(l_5, w_5), (1, 2), 3, q_5, v_5\}$
6	$f_6^2 = \{(l_6, w_6), (1, 2), 3, q_6\}$
7	$f_7^2 = \{(l_7, w_7), 1, 3, q_7\}$

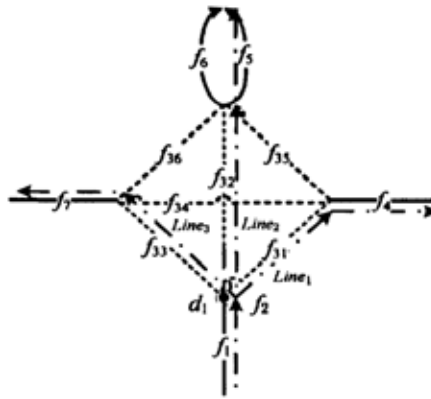


Fig. (9). The distribution service network of the target area.

Passenger transport organization contains passenger organization process and passenger flow line, and has directivity. As shown in Fig. (7), including three passenger flow lines, where, line 1 consists of facility No.1, 2, 3 and 4; line 2 consists of facility No.1, 2, 3 5 and 6; line 3 consists of facility No.1, 2, 3 and 7.

Guide service also has directivity, as shown in Fig. (8), where the directional sign  $d_1$  is set up located in the intersection.

### 5.2. Factor Description

Based on formula 2 and Fig. (6), the factor description of infrastructure is shown in Table 4, where, the width of facility No.3 is marked “+”, which meaning is big enough.

Based on formula 3 and Fig. (7), the link relations of facilities on the three passenger flow lines are as follows.

$$r_{line1} = (1, 2, 3, 4)$$

$$r_{line2} = (1, 2, 3, (5, 6))$$

$$r_{line3} = (1, 2, 3, 7)$$

Based on formula 4 and Fig. (8), the factor description of guide service is as follows.

$$d_1 = \{2, (line1, line2, line3), (4, 5, 6, 7)\}$$

### 5.3. Network Integration

The distribution service network of the target area is generated by superimposing Figs. (6), (7) and (8), as shown in Fig. (9).

### CONCLUSION

From the above-mentioned content, the conception of distribution service network is defined for the first time. Using the theory and method of system engineering, the property description model for distribution service network is established. The three-phrase modeling method and operation process are put forward, therewith, the model of distribution

service network is built, ultimately realizes the digital description. The case shows that this method has strong readability and operability. The article result can provide the basic environment for research on the comprehensive passenger transport hub.

### CONFLICT OF INTEREST

The authors confirm that this article content has no conflict of interest.

### ACKNOWLEDGEMENTS

This work is supported by the National Nature Science Foundation of China (71171015) and National High Technology Research and Development Program (2012AA-112403).

### REFERENCES

- [1] B.S. Verkhovsky, “Service networks topological design,” *International Journal of Communications, Network and System Sciences*, vol.3, pp. 850-854, 2010.
- [2] H. Wang, Z. Feng, and Y. Sui, “Service network: an infrastructure of web services,” In: *Proceedings of 2009 IEEE International Conference on Intelligent Computing and Intelligent Systems*, vol. 3, pp. 303-308, 2009.
- [3] S. Chen, and Z. Feng, “Service network: new basis points of web services composition,” *Application Research of Computers*, vol. 5, pp. 1378-1382, 2008.
- [4] E. Haihong, M. Song, and Song Junde, “The research of service network based on complex network,” In: *Proceedings of 2010 IEEE International Conference on Service Sciences*, pp. 203-207, 2010.
- [5] B. Hu, *Research on the Technology of Network Construction Based on Train Service Plan and Path Search and the Development of Computer System*, Beijing Jiaotong University, 2011.
- [6] S. Rui, *Research on the Service Network Design Theory and Method for Railway Express Parcel Transport*, Beijing Jiaotong University, 2006.
- [7] W. Xu, *Computational Techniques of Multimodal Service Network Capacity for Express Shipment*, Beijing Jiaotong University, 2010.
- [8] K.K.T. Lee, and P. Schonefeld, “Optimal slack time for timed transfers at a transit terminal,” *Journal of Advanced Transportation*, vol. 25, no. 3, pp. 281-308, 1991.
- [9] C. Guan, and Z. Wang, “Application of DEA in evaluation for urban passenger transfer hubs,” *Journal of Highway and Transportation Research and Development*, no. 9, pp. 145-149, 2008.



- [10] J.R. Seti, and B.G. Hutchinson, "Passenger-terminal simulation model," *Journal of Transportation Engineering*, vol. 120, no. 4, pp. 517-535, 1994.
- [11] Y.D. Lin, and A.A. Trani, "Airport automated people mover systems: analysis with a hybrid computer simulation model," *Transportation Research Record*, vol. 1703, pp. 45-57, 2000.
- [12] P.G. Gipps, and B. Marksjo, "A. micro-simulation model for pedestrian flows," *Mathematics and Computers in Simulation*, vol. 27, no. 2, pp. 95-105, 1985.
- [13] D. Helbing, "Collective phenomena and states in traffic and self-driven many-particle systems," *Computational Materials Science*, vol. 30, pp. 180-187, 2004.
- [14] W. Daamen, P.H.L. Bovy, and S.P. Hoogendoorn, "Influence of changes in level on passenger route choice in railway stations", In: *84<sup>th</sup> Annual Meeting of the Transportation Research Board*. Washington DC: NATL Research Council Press, pp. 12-20, 2005.
- [15] W. Daamen, P.H.L. Bovy, and S.P. Hoogendoorn, "Choices between stairs, escalators and ramps in stations," In: *10<sup>th</sup> International Conference on Computer System Design and Operation in the Railway and Other Transit Systems*. Prague, pp. 3-12, 2006.
- [16] H. Jia, B. Sun, and Q. Luo, "Measurement and adaptation analysis of their facilities capacity for the subway passenger terminal," *Journal of Jilin University (Engineering Edition)*, vol. 39, no. 2, pp. 199-203, 2009.

---

Received: October 16, 2014

Revised: December 23, 2014

Accepted: December 31, 2014

© Long et al.; Licensee Bentham Open.

This is an open access article licensed under the terms of the Creative Commons Attribution Non-Commercial License (<http://creativecommons.org/licenses/by-nc/3.0/>) which permits unrestricted, non-commercial use, distribution and reproduction in any medium, provided the work is properly cited.