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Research Article

Concept Layout Model of Transportation Terminals

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Transportation terminal is the key node in transport systems. Efficient terminals can improve operation of passenger transportation networks, adjust the layout of public transportation networks, provide a passenger guidance system, and regulate the development of commercial forms, as well as optimize the assembly and distribution of modern logistic modes, among others. This study aims to clarify the relationship between the function and the structure of transportation terminals and establish the function layout design. The mapping mechanism of demand, function, and structure was analyzed, and a quantitative relationship between function and structure was obtained from a design perspective. Passenger demand and terminal structure were decomposed into several demand units and structural elements following the principle of reverse engineering. The relationship maps between these two kinds of elements were then analyzed. Function-oriented concept layout model of transportation terminals was established using the previous method. Thus, a technique in planning and design of transportation structures was proposed. Meaningful results were obtained from the optimization of transportation terminal facilities, which guide the design of the functional layout of transportation terminals and improve the development of urban passenger transportation systems.

1. Introduction

With the accelerated urbanization and motorization, construction of transportation terminals in major cities in China is gradually approaching the ideal. The operating efficiency of terminals, which are key nodes in the transportation network, directly influences the efficiency of transportation networks. However, the occurrence of passenger interleaving and long-distance walking due to deficiencies in the layout of transportation terminals result in a low operating efficiency. This problem is aggravated with the increase in transportation demand.

In many advanced cities, planning, design, and management of transportation terminals adaptive to their cities have been investigated since the 1950s to alleviate traffic congestion [1–3].

Batarliene and Jarašuniene [4] studied the interaction between different transport modes in transport terminals. Piccioni et al. [5] gave an application for facility location and optimal location models. Some scholars succeeded in the study of traffic characteristics of pedestrian. Lam et al. [6, 7] and Young Seth [8] obtained pedestrian walking speed at different facilities. Cheung and Lam [9, 10], Lee and Lam [11] and Delft [12] explained the pedestrian flow characteristics and route selection rule at subway stations and simulated facility service level. Progress in researches about characteristics and evolution law of the weaving behaviors of pedestrian flow in transport terminals has also been achieved. Henderson [13] analyzed the statistical characteristics of high density pedestrian flow. Satish et al. [14], Laxman et al. [15], and Lam et al. [16] studied the characteristics of pedestrian flow at certain transportation facilities. The relationship between pedestrian speed and density was studied by Ando et al. [17], Thompson and Marchant [18], Hughes [19], Hankin and Wright [20], and so on. All the achieved results formed a base for the planning, design, and management of transportation terminals. The study of public passenger transportation planning and design in China began in the 1990s. Among the successful efforts were the development of a technique that allows cooperation of public traffic and the subway, evaluation of joining coordination degree, streamline analysis of transfers, optimization of cohesive systems of transportation terminals, calculation of the main function of key facilities, and the optimized layout design of transportation terminals [21–23].

A number of local and international achievements in planning and design of transportation terminals have been reported; however, a traditional architectural design is usually used, without consideration and analysis of the traffic function of terminals as well as the matching facilities. Traditional architectural design cannot meet the demand of modern and efficient transportation terminals. The layout or design should be suitable for transportation structures such as transportation terminals. This study uses the decomposition and reconstitution mechanism in industry design to study the relationship maps between demand, function, and structure. The study also searches for a transportation terminal design based on demand, which will eventually provide a new method for the layout of transportation terminals.

The remainder of the paper is structured as follows. Section 2 briefly introduces the basic methods of concept layout model. Section 3 forms a concept layout model of transportation terminal based on mapping mechanisms among demand, function, and structure, followed by the conclusions in Section 4.

2. Basic Method

Apart from ordinary architectural structures and basic structural functions, transportation terminals play specific functions for traffic, business, and civil aviation. Thus, creating a layout of transportation terminals is a complex task. Such layout differs from those of ordinary architectural structures. This study proposes a new layout that satisfies the demand of both passengers and structures. The layout is developed from the perspective of passenger demand for efficient transportation terminals and maximum operating efficiency.

This study analyzes the different characteristics of passengers' demand and the structure of facilities. To clarify the uncertainty and multiplicity of the relationship maps between demand and structure, the function layer was formed as the medium. A concept layout model of transportation terminals based on the relationship maps between demand, function, and structure was examined.

3. Concept Layout Model of Transportation Terminals

3.1. Mapping Mechanisms among Demand, Function, and Structure

Passengers engage in a series of activities inside and outside transportation terminals. These activities include purchasing tickets, security inspection, ticket checking, waiting, line transferring, boarding and alighting, and shopping. Each activity corresponds to an area within the terminal. However, the demand of passengers and the structure facilities of terminals are complicated. A passenger needs a series of structural facilities at certain times, and each structure can satisfy various passenger demands. To solve such problems, a functional transport layer has been established between passenger demands and structural facilities. This layer simulates human thinking.

Aimed at unifying demand, function, and structure, this paper first analyzed the original demand of passengers, the objective law of evolution of terminal function, and the characters of terminal structure facilities. For a certain passenger demand R_i, the corresponding function element F_i can be inversely decomposed. Facility elements of terminal structure can simultaneously be decomposed to form the mapping combination $C_i = \{R_i, F_i, S_i\}$ in Figure 1.

3.2. Concept Layout Model

Passenger demand in transportation terminals can be divided into several subdemands such as transportation, business, architecture, and civil aviation, among others, as shown in the first layer in Figure 2. Transportation demand is the core among the four sub-demands. Each subdemand can be divided into several demand units. For instance, let subdemand 1 represent transportation demand. Transportation demand can be divided into demand units such as transferring, waiting, buying tickets, parking, and coming in and out of the station.

To determine the functions of the demand units, corresponding structure facilities are needed. For example, to realize transfer demand, facilities such as transfer halls, transfer channels, railings, transfer stairs, autoescalators, automoving walkways, and elevators are necessary.

Thus, all facilities needed to realize the functions of the terminal are listed and then grouped into different substructures.

In Figure 2, the facilities are divided into four sub-structures, which consist of the following: inside and outside the area, fare collection system, transferring system, and platform area.

Substructure 1 includes the security inspection equipment, elevator, stairs, automatic moving walkway, automatic escalator, and channel.

Substructure 2 includes the wicket, automatic ticket-selling machine, autoinquiry machine, autorecharge system, pulling in and out of the station point, supplementary ticket desk, inquiry office, and railing.

Substructure 3 includes the transfer hall, transfer channel, railing, transfer stairs, autoescalator, moving walkway, and elevator.

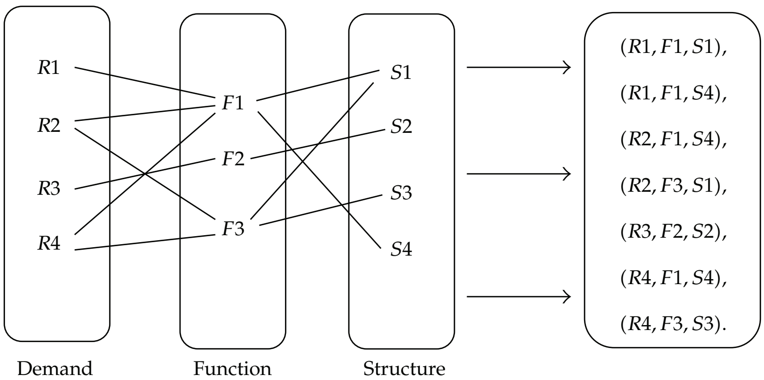

Figure 1: Relationships among demand, function, and structure.

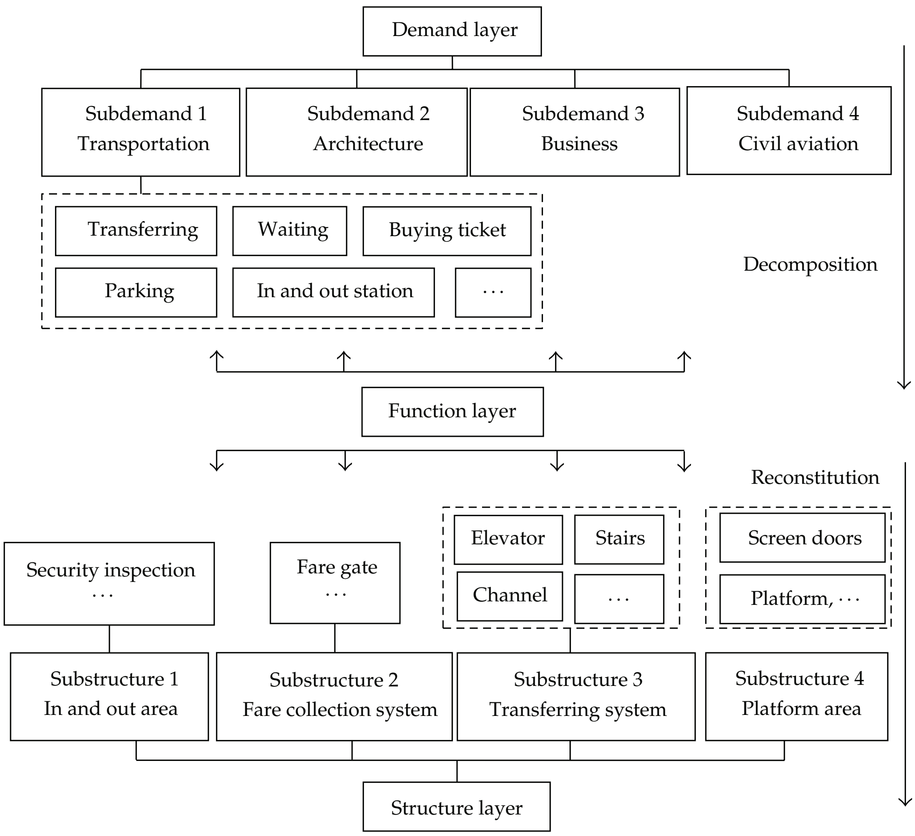

Figure 2: Decomposition and reconstitution of transportation concept layout model.

Substructure 4 includes the channel, elevator, auto-escalator, stairs, platform, and platform screen door.

Figure 2 shows the decomposition and reconstitution of transportation concept layout model.

3.3. Constraints of the Transportation Concept Layout Model

To form the detailed layout design, the growing elements must be calculated, including, the form, scale, relative position, and combination of cohesive primitive constraints of the facility. The key objective is to determine the constraints of all growing elements. With the aim of optimizing efficiency, this paper examines the calculation of the constraints of time utility, distance utility, and structure utility.

3.3.1. Constraint of Time Utility U_1

Time utility U_1 is the most important constraint in the calculation of growing elements of transportation terminals. U_1 is determined by the service level of facilities, passenger volume, adaptability relationship of the joining facilities, and so on. Time utility U_1 can be calculated by (3.1). The equation is explained by the arrival and departure of passengers in the terminal. Passengers are divided into four types: those arriving in mass and departing in mass, arriving individually and departing in mass, arriving in mass and departing individually, and arriving individually and departing individually

$$U_1 = \sum_{n=1}^{4} Q_n \left(\bar{t}_{n1} + \bar{t}_{n2} + \bar{t}_{n3} + \bar{t}_{n4} + \bar{t}_{n5} + \bar{t}_{n6} \right), \tag{3.1}$$

where Q_n is the passenger volume of kind n, $n = 1, 2, 3, 4$; $\bar{t}_{n1}$ is the average time required for type n passenger to buy tickets; $\bar{t}_{n2}$ is the average time of security inspection for type n passenger; $\bar{t}_{n3}$ is the average time required for type n passenger to arrive at the station; $\bar{t}_{n4}$ is the average waiting time for type n passenger; $\bar{t}_{n5}$ is the average time required for passenger n to depart from the station; and $\bar{t}_{n6}$ is the average transfer time between different traffic modes or lines for type n passenger.

3.3.2. Constraint of Distance Utility U_2

Distance utility U_2 represents the basic constraint in the calculation of growing elements of transportation terminals. U_2 is determined by the relative position of facilities in passengers' walking streamline, as shown in (3.2)

$$U_2 = \sum_{m=1}^{M} Q_m \bar{d}_m, \tag{3.2}$$

where M is the number of transfer traffic modes; Q_m is the passenger volume of traffic mode m; and $\bar{d}_m$ is the average transfer walking distance of traffic mode m.

3.3.3. Constraint of Structure Utility U_3

Structure utility is the basic constraint in the calculation of growing elements of transportation terminals, which is determined by the facility plot ratio φ, organizational order of streamline η and facility correlation degree θ, as shown in (3.3)

$$U_3 = \varepsilon_1 + \eta\varepsilon_2 + \theta\varepsilon_3, \\ \varepsilon_1 + \varepsilon_2 + \varepsilon_3 = 1, \tag{3.3}$$

where $\varepsilon_1 > 0,\ \varepsilon_2 > 0,\ \varepsilon_3 > 0$; φ is the facility plot ratio; η is the organizational order of streamline; θ is the degree of facility correlation; ε_1 is the weight of the facility plot ratio; ε_2 is the weight of organizational order of streamline; and ε_3 is the weight of the degree of facility correlation.

The facility plot ratio is determined by the average ratio of the effective facility utilization area S_I and the whole utilization area of the transportation terminal S_C, as shown in (3.4). The greater the plot ratio, the more reasonable the structure design

$$\varphi = \frac{1}{k}\sum_{i=1}^{k}\left(\frac{S_I}{S_C}\right)_i, \tag{3.4}$$

where k is the number of facility elements of terminals.

The organizational order of the streamline reflects the intereffect of each streamline, which is determined by the ratio of the total number of conflict points of the streamline H_0 and the total number of facility nodes of the streamline H_1, as shown in

$$\eta = 1 - \frac{H_0}{H_1}. \tag{3.5}$$

Facility correlation degree is determined by the combined correlation value of each node of the streamline, as shown in (3.6). The greater the facility correlation degree, the more reasonable the structure design

$$\theta = \frac{1}{m}\sum_{i=1}^{m}\left[\frac{1}{r_i}\sum_{j=1}^{r_j}\left(\frac{n_{(j,j+1)} \cdot d_{(j,j+1)}}{\sum_{i=1}^{m} n_{(j,j+1)} \cdot d_{(j,j+1)}}\right)\right], \tag{3.6}$$

where m is the number of streamlines in the facility, r_i is the number of facilities at the node of the streamline i; $n_{(j,j+1)}$ is the total number of passengers between the facility node j and the facility node $j+1$; and $d_{(j,j+1)}$ is the walking distance from the facility node j and the facility node $j+1$.

4. Conclusion

A transportation terminal design is established. The relationship between the function and the structure of transportation terminals is examined in this study. Following the principle of reverse engineering, the whole function and structure of the transportation terminal was decomposed into several demand units and elements of a facility structure. Transportation demand can be divided into subunit demands such as transferring, waiting, buying ticket, parking, and coming in and out of the station, among others. Facilities are divided into four sub-structures: inside and outside the area, fare collection system, transfer system, and platform area. Furthermore, the calculation methods of the constraints of time, distance, and structure utilities are given. Based on this, the function-oriented concept layout model of transportation terminals is established to provide a new method for planning and designing transportation structures.

Future studies should focus on the quantitative description of the demand units and structure facilities.

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