An Optimal Plan of Transportation Terminals in Metropolitan Area

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Abstract. Development of metropolitan area in China has attracted a lot of attention. At this stage, planning of transportation terminals focuses on cities, rather than metropolitan area. In order to achieve the goal of transport integration, it is crucial to propose an optimal plan of transportation terminals in metropolitan area. This paper proposes a coherent set of method to optimize transportation terminals in metropolitan area, including classification of cities and planning of transportation terminals. Classification of cities is based on hierarchical clustering method, and planning of transportation terminals is based on classification standards of the multimodal transportation terminal. Then a case study in Jingjinji metropolitan area has been verified. This method has advantages of less data, simplicity and compatibility of existing terminals. On the basis of exiting and planning terminals, the integrated transit system can be built.

1. Introduction

A transportation terminal is the junction of regional population and traffic flow, and also the fulcrum of social and economic development, playing an important role in the traffic system in metropolitan area. At the present stage, the domestic research of transportation terminals mainly focuses on the urban level, but neglects the application in metropolitan area. Transportation terminals in metropolitan area have the following four problems: (1) compared with traffic networks, the government does not invest enough money in the construction of transportation terminals; (2) regional terminals lack all-round planning and management, and terminal planning is unreasonable; (3) there is a lack of connection among different means of transport, and transportation terminals develop slowly, and (4) commercial land development around terminals can not meet the purpose of trip. Therefore, it is essential to make an effort to study planning of transportation terminals in metropolitan area.

This paper puts forward the process of transportation terminals planning in metropolitan area. It includes several steps as followed: (1) selecting various economic indexes, and using hierarchical clustering method to classify cities; (2) considering dominant means of transportation to categorize transportation terminals; and (3) combining classification of cities, traffic demand, urban geographic location and other factors to plan transportation terminals in metropolitan area. Also, this paper proves the feasibility and efficiency of the process with a case study in Jingjinji metropolitan area(including Beijing, Tianjin and Hebei province).
2. An optimal plan of transportation terminals

2.1. Classification of cities based on hierarchical clustering method

2.1.1. Hierarchical clustering method

The idea of hierarchical clustering method [1] in planning of transportation terminals is as followed:
Firstly, each city in the region is regarded as a category, as class 1, class 2, ... Class n, and there are a series of variables \( \{x_k\} \) (where \( k \) is 1, 2, ... \( m \)) to describe its characteristics. Then, the two most similar categories of these \( n \) classes are merged into a new class, and \( n-1 \) classes are obtained. Next, the two most similar categories in these \( n-1 \) classes are merged into another new class, and \( n-2 \) classes are obtained. Finally, the rest can be done in the same manner as mentioned before, until all cities are merged into a single class. The similarity between two cities can be defined as followed:

\[
G_i \text{ and } G_j \text{ are alternative city classes. } d_{ij} \text{ represents the similarity (also known as distance) between city } i \text{ from } G_i \text{ and city } j \text{ from } G_j, \text{ and } D_i(r,s) = \min \{ d_{ij} \mid i \in G_r, j \in G_s \} \text{ is the shortest distance between } G_i \text{ and } G_j \text{ (} i, j = 1, 2, \ldots n \text{). Euclidean distance is frequently used to calculate } d_{ij}, \text{ as shown in equation (1).}
\]

\[
d_{ij} = \sqrt{\sum_{k=1}^{m} (x_{ik} - x_{jk})^2} \tag{1}
\]

The evaluation indexes of each alternative city should be normalized during the calculation of Euclidean distance.

2.1.2. Classification of cities

Hierarchical clustering method with economic and traffic indexes is exerted to classify cities. There are four city classes: (1) international traffic point city: a transport system includes the international airport and the national or regional high-speed railway terminal; (2) national traffic point city: a transport system includes the national airport and the national or regional high-speed railway terminal; (3) regional traffic point city: a transport system includes the regional airport and the regional high-speed railway terminal, and (4) general traffic point city: a transport system includes the general railway terminal [2].

2.2. Classification of transportation terminals

The research on classification standards of transportation terminals in cities mainly focuses on the transportation terminal with one means of transportation, while the research on multimodal transportation terminals mainly concentrates on qualitative analysis [3,4]. Based on the classification standards summarised by domestic and foreign scholars [5], this paper adopts classification standards of "Classification of multimodal passenger transportation hub" [6] and divides the multimodal transportation terminal into the following four types.

(1) Aviation-based multimodal transportation terminal: a traffic system relies on an airport with railways, highways and urban traffic;

(2) Railway-based multimodal transportation terminal: a traffic system relies on a railway terminal (except for one which only has intercity railways) with highways and urban traffic.

(3) Waterborne-based multimodal transportation terminal: a traffic system relies on a port with highways and urban traffic.

(4) Highway-based multimodal transportation terminal: a traffic system relies on a highway terminal with intercity railways and urban traffic.

According to the total passenger delivery volume of the multimodal transportation terminal and the total passenger delivery volume of external transport mode in the design year, the multimodal transportation terminal is divided into 4 classes. Classification standards are shown in table 1 [6].
Table 1. Classification standards of the multimodal transportation terminal.

| Class      | Aviation-based | Railway-based | Highway-based | Waterborne-based |
|------------|----------------|---------------|---------------|------------------|
|            | TPDVMTT        | TPDVE TAM     | TPDVM TT      | TPDVMTT          |
| Class one  | ≥20            | ≥10           | ≥10           | ≥10              |
| Class two  | [10,20)        | [5,10)        | [6,10)        | [2,10)           |
| Class three| [5,10)         | [2,5)         | [2,6)         | [1,3)            |
| Class four | <5             | <2            | <2            | <1               |

2.3. Planning process

For different dominant means of transportation, there are several different indexes selected to plan terminals. Planning is based on classification of cities determined by hierarchical clustering method. "Classification of multimodal passenger transportation hub" is adopted as the planning standard. Also, this planning combines exiting urban transportation terminals with planning transportation ones. Planning is also expected to satisfy requirements of urban planning and travel demands in the design years. The planning process of transportation terminals in metropolitan area is shown in Figure 1.

3. A case study in Jingjinji metropolitan area

3.1. Classification of cities in Jingjinji metropolitan area

There are 13 cities in Jingjinji metropolitan, which are regarded as the original classes. The data are derived from "CHINA CITY STATISTICAL YEARBOOK" [7]. Time series prediction method [8] is used in this paper to predict values of each city’s population, gross domestic production and total
passenger delivery volume in 2020. These indexes are adopted to cluster cities. Indexes of each city are shown in table 2.

| City             | Population (ten thousand people) | GDP (hundred million RMB) | traffic volume (ten thousand people) |
|------------------|----------------------------------|---------------------------|--------------------------------------|
| Beijing          | 2264                             | 31921                     | 83137                                |
| Tianjin          | 1844                             | 24648                     | 23846                                |
| Shijiazhuang     | 1125                             | 7672                      | 12189                                |
| Chengde          | 359                              | 1936                      | 3718                                 |
| Zhangjiakou      | 451                              | 1936                      | 5126                                 |
| Qinhuangdao      | 316                              | 1667                      | 3600                                 |
| Tangshan         | 809                              | 7056                      | 6212                                 |
| Langfang         | 476                              | 3436                      | 8070                                 |
| Baoding          | 1204                             | 4769                      | 13565                                |
| Cangzhou         | 778                              | 4709                      | 6116                                 |
| Hengshui         | 456                              | 1715                      | 2603                                 |
| Xingtai          | 747                              | 2381                      | 6446                                 |
| Handan           | 967                              | 3532                      | 14108                                |

(1) Each city is regarded as a category. There are 13 categories, which are represented by the sequence, \{u1\}, \{u2\}, ..., \{u13\}.

(2) Normalizing indexes of each city to calculate their distances, as shown in equation (2) - (4).

\[
G_1 = \begin{bmatrix}
G_{11} & G_{12} & G_{13} \\
G_{21} & G_{22} & G_{23} \\
G_{31} & G_{32} & G_{33}
\end{bmatrix}
\]

\[
G_2 = \begin{bmatrix}
G_{11} & G_{12} & G_{13} \\
G_{21} & G_{22} & G_{23} \\
G_{31} & G_{32} & G_{33}
\end{bmatrix}
\]

\[
G_3 = \begin{bmatrix}
G_{11} & G_{12} & G_{13} \\
G_{21} & G_{22} & G_{23} \\
G_{31} & G_{32} & G_{33}
\end{bmatrix}
\]

\[
G_{13} = \begin{bmatrix}
G_{11} & G_{12} & G_{13} \\
G_{21} & G_{22} & G_{23} \\
G_{31} & G_{32} & G_{33}
\end{bmatrix}
\]

The lower triangular matrix \(D^{(0)}\) of the distance matrix can be obtained by using the normalized matrix and the aforementioned Euclidean distance \(d_{ij}\). The first iteration result is shown Figure 2.

![Figure 2. the first iteration result.](image-url)
(3) Merging two classes with minimum distance to create a new class. The group with the minimum distance in $D^{(0)}$ is $d_{5,11} = 0.031$, so $G_5$ and $G_{11}$ are merged to create the new class $G_{14} = \{G_5, G_{11}\}$, and the original two classes are cancelled.

(4) Defining distance as similarity. The distance between the new class $G_{14}$ and remaining classes separately like $d_{14,1} = \min\{d_{1,5}, d_{1,11}\} = \min\{1.551, 1.572\} = 1.551$ are calculated, then a new distance matrix $D^{(1)}$ is created.

(5) Repeating steps (3) and (4) until all original classes are merged into one class. A diagram is drawn to show the clustering process, as shown in figure 3.

(5) Obtaining the final classification. According to the clustering process, 13 cities in Jingjinji metropolitan area are divided into 4 classes, i.e. $\{1,2\}$, $\{3,9,13\}$, $\{7,10,12\}$, $\{5,11,4,6,8\}$. Classification of cities is shown in Table 3 [9].

| Classification of cities | City |
|--------------------------|-----|
| International traffic point city | Beijing, Tianjin |
| National traffic point city | Shijiazhuang, Baoding, Handan |
| Regional traffic point city | Tangshan, Qinhuangdao, Cangzhou, Xingtai |
| General traffic point city | Zhangjiakou, Hengshui, Chengde, Langfang |

3.2. An optimal plan in Jingjinji metropolitan area

According to classification of cities and classification standards of the multimodal transportation terminal, transportation terminals in Jingjinji metropolitan area are optimized. Planning results of aviation-based and railway-based transportation terminals are shown in Figure 4.

The optimal plan of aviation-based transportation terminals can achieve cooperation among different aviation terminals. In this way, regional resources are shared. Additionally, openness of the metropolitan area is promoted, and space for urban development is broadened. The optimal plan of railway-based transportation terminals can satisfy regional traffic demands and take advantage of exiting railway networks to strengthen interregional economic interaction [10,11].
4. Conclusions
This paper plans transportation terminals in metropolitan area from the perspective of traffic point city. Hierarchical clustering method with appropriate economic indexes is used to classify cities. Planning results are subjected to multiple restrictions, including existing facilities, urban planning, traffic demands and so forth. With the proposed planning progress, a case study in Jingjinji metropolitan area has been verified, and planning results of aviation-based and railway-based transportation terminals have been presented. This method provides a straightforward and feasible plan of transportation terminals, which can be applied in other metropolitan areas of China.

Acknowledgement
This study was supported by Key Projects of Basic Scientific Research Operating Expenses under Grant NO. 2017JBZ106 (Research on the theory and method of urban traffic system collaborative planning, design and operation).

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