COUPLING MODEL FOR MULTIMODAL TRANSFER FACILITIES AT URBAN RAIL STATIONS: AN ANALYSIS OF LELYLAAN STATION, AMSTERDAM

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Word count:

Words: 4666
Tables: 3 x 250 = 750
Figures: 7 x 250 = 1750
Total: 7166

Submitted for presentation and publication for the 93rd annual meeting of the Transportation Research Board, 12-16 January 2014
ABSTRACT

Multimodal transfer at urban rail station has good effects to yield a larger usage of the urban rail transit system, and at the same time may alleviate the traffic load on the urban road network. However, urban rail transit heavily relies on the access and egress transit, hence on the corresponding transfer facilities. Therefore, passengers’ choice depends on the design of transfer facilities at urban rail station area to a great extent. An improvement in these transfer facilities is to promote integration level, which may attract passengers to urban rail transit more conveniently. In this paper, we focus on the transfer coupling status of multimodal transfer facilities at urban rail stations. To this end, multimodal transfer system at urban rail stations is dissected regarding urban rail transit trip chain from origin to destination and multimodal modes in station area. Transfer distance matrix is proposed as a useful tool to show equivalent walking distance (EWD) between transfer facilities to urban rail transit, which shows types of transit facilities, location and number of all facilities and practical walking distance clearly during access transfer trip and egress transfer trip. Multimodal transfer coupling concept at urban rail station is put forward to analyze integration level problem, after which transfer coupling model is established, including transfer coupling degree for multimodal modes and different entrances. Field observation of urban rail station was conducted at Lelylaan station in the city of Amsterdam, and coupling status analysis derived from the collected data is discussed. The models could have a reasonably good fit to practical case, and the findings presented in this study are thus directly valuable for planners and designers aimed at improving urban rail transit ridership.
INTRODUCTION

Urban rail transit is the most important mode in public transport system, which plays a pivotal role in society life. As known, multimodal transfer at urban rail station has good effects to yield a larger usage of the urban rail transit system, and at the same time may alleviate the traffic load on the urban road network [1]. However, urban rail transit heavily relies on the access and egress transit, hence on the corresponding transfer facilities. Transfer facilities of urban rail stations include bus stops (tramway stops), parking lots for P&R, B&R, K&R, taxi boarding area, etc. The main service groups for such facilities are found to be travelers with more than 15 minutes walking distance from the metro station [2]. Therefore, passengers’ choice depends on the design of transfer facilities at urban rail station area to a great extent. An improvement in these transfer facilities is to promote integration level, which may attract passengers to urban rail transit more conveniently.

A number of studies have been conducted on transfer services with respect to urban rail transit, where most of this research has focused on improving intermodal transfer for bus-rail transport or bicycle-rail transport. In spite of more focus on multimodal transportation system in recent years, multimodal transfer at urban rail station has received less attention from urban transport policy makers and planners. Brown and Thompson discuss the relationship between service orientation, bus-rail service integration, and transit performance in a number of U.S. metropolitan areas [3]. In a study by Seaborn et al. [4], bus-metro transfer combinations are considered, and recommendations are made on the maximum elapsed time thresholds in order to identify transfers between journey stages for the passengers on the London underground network. Lijun concludes that the determinants for travelers making use of bicycle transferring facilities (BPF) are found to be the distance between their origin and the BPF, when walking is the alternative access/egress mode [2].

In Shaokuan’s research, a hierarchical network and traffic assignment model is developed for multimodal transportation networks to meet the prediction of large-scale transportation demand [5]. Stephan found that initiatives aimed at improving access and egress hold potential to significantly reduce public transport trip time and are inexpensive options compared to the expensive infrastructure and vehicle enhancements [6]. Jianwei tries to develop and test a generic multimodal transport network model for ATIS applications [7]. Besides, Li discusses optimization technology of the configuration of joint transportation resources at urban rail passenger station [8]. A comparative analysis hereon is made by Lijun and Xuewu, exploring transfer facilities configuration method of urban rail station in China [9]. This clearly argues in favor of improving multimodal transport system, and thereby relating to network, access and egress trip, transfer resources, etc.

The concept coupling which commonly used in multidisciplinary (communication engineering, software engineering, mechanical engineering, physics, etc. [10-14]), is introduced into multimodal transfer system in this research to show integration level of transfer facilities and urban rail transit. The reason for this is shown to be related to interaction and correlative dependence of two systems [15], which also accord with the characteristics of multimodal transfer system with regard to urban rail transit. This is supported by, for example, observations on coupling development of urban rail transit and urban space [16].

In this paper, we focus on the transfer coupling status of multimodal transfer facilities at urban rail stations. The findings presented in this study are thus directly valuable for planners and designers aimed at improving urban rail transit ridership. To this end,
multimodal transfer system at urban rail stations is dissected regarding urban rail transit trip chain from origin to destination and multimodal modes in station area. Furthermore, transfer distance matrix is proposed as a useful tool to show equivalent walking distance (EWD) between transfer facilities to urban rail transit, which shows types of transit facilities, location and number of all facilities and practical walking distance clearly during access transfer trip and egress transfer trip. The third section discusses multimodal transfer coupling concept at urban rail station, after which transfer coupling model is established, including transfer coupling degree for multimodal modes and different entrances. Then field observation of urban rail station was conducted at Lelylaan station in the city of Amsterdam, and coupling status analysis derived from the collected data is discussed. The final section makes a number of concluding remarks regarding the main findings and the practical implications hereof for multimodal transfer coupling.

MULTIMODAL TRANSFER AT URBAN RAIL STATIONS

Multimodal Transfer System at Urban Rail Stations

When passengers choose urban rail transit mode, they have to realize trips with the help of bus, bicycle, car, taxi, etc. The whole trip chain from origin to destination consists of three parts, i.e. access transfer trip, urban rail transit trip and egress transfer trip (see Figure 1). Access transfer trip is defined as the course from origin to first urban rail station while egress transfer trip is the course from last urban rail station to destination.

![Urban rail transit trip chain from origin to destination](image)

Around urban rail stations, multimodal transfer system is developed step by step to satisfy transfer demand for passengers, including bus, B&R, P&R, taxi, etc. Normally, these modes occupy different resource in the station area (see Figure 2). For example, according to geological conditions urban rail lines use exclusive way in the form of tracks as underground lines, ground lines or elevated lines. Bus lines are usually designed along high grade urban roads, some of which have high priority as bus transit lane, i.e. BRT. Furthermore, car, bicycle and taxi occupy same road resource no matter of road grades. In a word, such modes supply transfer service to urban rail transit mode making use of different road resource, then constitute multimodal transfer system for urban rail stations combine with transfer facilities.
Transfer Distance Matrix at Urban Rail Stations

Transfer facilities of urban rail stations include bus stops (tramway stops), parking lots for cars and bicycles, taxi boarding area, etc. In urban rail station area, multimodal transfer facilities layout should be designed compactly as to shorten passengers’ transfer walking distance to entrances of urban rail stations. Panoramagram of station area including all multimodal transfer facilities could be described in form of stereogram to show location and routes how to transfer between facilities to entrances. Figure 3 shows a typical multimodal transfer facilities layout panoramagram of Lelylaan station area, Amsterdam. From this picture, surroundings of the station including road, tracks, lines directions, layout levels, facilities location could be seen clearly so that researchers would have a general impression of station.

As introduced above, it is found that multimodal transfer facilities layout is the base of transfer distance matrix. During access transfer trip and egress transfer trip, transfer distance matrix is defined as a useful tool to understand four elements of transfer as plain as print, such as current transit modes, type of transit facilities, location and number of all facilities (entrances, parking lots, stops, boarding area, etc.) and practical walking distance. Here, equivalent walking distance (EWD) is put forward to express practical walking distance in matrix, including measurable walking distance (MWD), road crossings distance (RCD), ascending and descending steps distance (ASD), elevator distance (ED). EWD is the sum of MWD, RCD, ASD, ED.

Table 1 shows a simple example of transfer matrix design, the detailed four design elements of transfer distance matrix are as follows:

- code of current transit modes: urban rail transit (M), train (T), tramway (P), bus (B), P&R (PR), B&R (BR), taxi (TP), K&R (KR).
- type of transit facilities: entrances of urban rail transit and train, stops of bus and tramway, parking lots for cars and bicycles, boarding area for taxies and K&R cars.
- location and number of all facilities: number of entrances, parking lots, stops, boarding lots.
- practical walking distance: EWD between facilities.
Table 1 Design of Transfer Matrix (unit:m)

<table>
<thead>
<tr>
<th>Transfer Matrix</th>
<th>location</th>
<th>underground</th>
<th>ground</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>code</td>
<td>Urban rail transit</td>
<td>Bicycle</td>
</tr>
<tr>
<td>location</td>
<td>code</td>
<td>entrance M1 M2 BP1 BP2 B1 B2</td>
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<tr>
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<td>B1</td>
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<td></td>
<td>B2</td>
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</table>

Multimodal Transfer Coupling at Urban Rail Station

Coupling is introduced into multimodal transfer system of urban rail station to express integration degree between urban rail transit mode and other transfer modes. In order to realize multimodal integration then develop a sustainable comprehensive transportation system, transfer facilities and their reasonable configuration are important integration carriers to attract more passengers to urban rail transit. Multimodal transfer coupling makes bus, tramway, bicycle, car and taxi not only single transport modes but also effective transfer modes at urban rail station. It produces a coupling strength to connect and join multimodal modes together and cultivate more public passenger flow, which could be measured by transfer coupling degree.

Transfer coupling development includes three stages (see Figure 4) according to architecture construction and function evolution. The first stage is called system architecture evolution, in which designers and managers construct some transfer facilities based on urban rail station land use conditions and transfer demand from step to step. Existence of transfer facilities could guide people to choose urban rail transit. The second
stage is to realize function improvement and perfection, during which managers observe and investigate service situation of transfer facilities and find shortcomings. This stage lasts 3 to 5 years, and main tasks are to increase or decrease facilities scale, change facilities types, and maintain facilities, etc. Integration level between urban rail transit and transfer facilities enhance from preliminary coordination to critical coupling and finally keep stable.

FIGURE 4 Transfer coupling development stages

TRANSFER COUPLING MODEL AT URBAN RAIL STATIONS

Coupling degree is a key indicator to show integration level of transfer facilities and urban rail station, which is defined as product of transfer distance coupling coefficient and passenger transfer flow coefficient. In this research, two aspects are thought of in transfer coupling model at urban rail stations. On one hand, two modes coupling that urban rail transit oriented transfer is considered in the multimodal system at urban rail stations. On the other hand, multimodal transfer coupling at different entrances is also researched to show the difference of facilities configuration in station area.

Transfer Coupling Degree for Multimodal Modes

Step 1: Range standardization of transfer distance matrix

Assume that there are N entrances at one urban rail station, which is noted as \( M_i \) \( (i=0,1,\ldots, n) \). Transfer distance matrix is established by data collection, from which EWD between entrances of urban rail station to transfer facilities could be known very clearly and quickly. The value of \( z_{ij} \) is between 0 and 1.

\[
z_{ij} = \frac{X_{ij} - \min_i X_{ij}}{\max_i X_{ij} - \min_i X_{ij}}\tag{1}
\]

Where: \( X_{ij} \) is EWD between entrances of urban rail station to transfer facilities in matrix, \( i \) is row in matrix, \( j \) is column in matrix, \( z_{ij} \) is standardized EWD between entrances of urban rail station to transfer facilities.
\[ Z_{ij} = \begin{bmatrix} z_{11} & \cdots & z_{1k} \\ \vdots & \ddots & \vdots \\ z_{n1} & \cdots & z_{nk} \end{bmatrix} \]  

(2)

Step 2: Transfer distance coupling coefficient

Transfer distance coupling coefficient \( C_d \) is calculated as follows:

\[ C_d = \frac{1}{n} + \frac{1}{k} * \sum_{j=1}^{n} \sum_{i=1}^{k} Z_{ij} \]  

(3)

Step 3: Facilities capacity coupling coefficient

Facilities capacity coupling coefficient \( C_q \) is calculated respectively as follows:

\[ C_q(bike) = N(bike) * \theta_{bike} * \rho_{bike} / Q(bike) \]  

(4)

Where: \( C_q(bike) \) is capacity coupling coefficient of bicycle parking facilities, \( N(bike) \) is number of bicycle parking lots, \( \theta_{bike} \) is turnover ratio of bicycle parking lots per day, \( \rho_{bike} \) is utilization ratio of bicycle parking lots per day, \( Q(bike) \) is bicycle transfer flow volume.

\[ C_q(bus) = N(busline) * f_{bus} * \rho_{bus} / Q(bus) * q_{bus} \]  

(5)

Where: \( C_q(bus) \) is capacity coupling coefficient of bus stops, \( N(busline) \) is number of bus lines, \( f_{bus} \) is average departure frequency of bus, \( \rho_{bus} \) is proportion of bus transfer passenger flow per bus, \( Q(bus) \) is bus transfer passenger flow volume, \( q_{bus} \) is average capacity per bus.

\[ C_q(car) = N(car) * \theta_{car} * \rho_{car} / Q(car) \]  

(6)

Where: \( C_q(car) \) is capacity coupling coefficient of P&R facilities, \( \theta_{car} \) is turnover ratio of car parking lots per day, \( \rho_{car} \) is utilization ratio of car parking lots per day, \( Q(car) \) is P&R transfer passenger flow volume.

\[ C_q(taxi) = N(taxi) * q_{taxi} / Q(taxi) \]  

(7)

Where: \( C_q(taxi) \) is capacity coupling coefficient of taxi boarding lots, \( N(taxi) \) is statistical number of taxi transfer, \( q_{taxi} \) is average passenger capacity per taxi, \( Q(taxi) \) is taxi transfer passenger flow volume.

Step 4: Comprehensive coupling degree

Comprehensive coupling degree is defined as product of transfer distance coupling coefficient and passenger transfer flow coefficient, which is calculated as follows:

\[ C_{tot} = C_d * C_q \]  

(8)
\[ C_{total}(\text{bike}) = \frac{1}{n} \sum_{i=1}^{n} \sum_{j=1}^{k} Z_{ij} * N(\text{bike}) * \theta_{bike} * \rho_{bike} * Q(\text{bike}) \]
\[ C_{total}(\text{bus}) = \frac{1}{n} \sum_{i=1}^{n} \sum_{j=1}^{k} Z_{ij} * N(\text{bus}) * \theta_{bus} * \rho_{bus} * q_{bus} * f_{bus} \]
\[ C_{total}(\text{car}) = \frac{1}{n} \sum_{i=1}^{n} \sum_{j=1}^{k} Z_{ij} * N(\text{car}) * \theta_{car} * \rho_{car} * Q(\text{car}) \]
\[ C_{total}(\text{taxi}) = \frac{1}{n} \sum_{i=1}^{n} \sum_{j=1}^{k} Z_{ij} * N(\text{taxi}) * q_{taxi} / Q(\text{taxi}) \]

Where: \( C_{total}(\text{bike}) \) is comprehensive coupling degree of bicycle transfer to urban rail transit, \( C_{total}(\text{bus}) \) is comprehensive coupling degree of bus transfer to urban rail transit, \( C_{total}(\text{car}) \) is comprehensive coupling degree of P&R to urban rail transit, \( C_{total}(\text{taxi}) \) is comprehensive coupling degree of taxi transfer to urban rail transit.

**Coupling Degree for Different Entrances at Urban Rail Stations**

It is observed that multimodal transfer coupling at different entrances in the station area has different features since different types of transfer facilities locate at different entrances. In access transfer trip, passengers always try to get into urban rail transit by nearest entrance from transfer facilities after they arrive at the station area. However, passengers get out of station by entrance which is nearest to the place when they arrive at the platform, but this entrance is not necessarily nearest to their mean transfer facilities. As a result, it is also a interesting topic to find coupling characteristics of transfer facilities clusters and entrances.

In this research, entrances are abstracted as nodes, from which number of transfer facilities are counted for access transfer trip and egress transfer trip as in-degree \((deg^+ (M_i))\) and out-degree \((deg^- (M_i))\). Then coupling degree is calculated as follows:

\[
 C(M_i) = deg^+ (M_i) \ast deg^- (M_i) \ast \frac{\sum_{i=1}^{n} \sum_{j=1}^{k} \| M_i - X_j \|}{n \sum_{i=1}^{n} \| M_i - X_j \|} \]  

(9)

Where: \( C(M_i) \) is coupling degree at entrance \( M_i \), \( \| M_i - X_j \| \) is EWD from entrance \( M_i \) to transfer facility \( X_j \).

**Distinguished Rules of Coupling Degree**

According to coupling theory, the value of coupling degree is between 0 to 1. The higher transfer coupling degree is, the better integration level will be. That is to say, with the increase of coupling degree, the connection relationship between transfer facilities and urban rail entrances improve. Furthermore, blood capillary effect happen that passenger flow accelerate the seepage from transfer facilities nodes to urban rail transit mode, then attract people to use public transport. Transfer coupling states includes three status, i.e. weak coupling, moderate coupling, tight coupling. Assume that \( C=1 \), here coupling state is tightest, while \( 0.65 < C \leq 1 \), it is tight coupling between urban rail transit to transfer facilities. In the similar way, assume that \( 0.35 < C \leq 0.65 \), it is moderate coupling, while \( 0 < C \leq 0.35 \), it is weak coupling.
COUPLING TRANSFER STATUS ANALYSIS

Before presenting the analysis of coupling transfer status, the process of data collection and layout of Lelylaan Station are discussed.

Data Collection at Lelylaan Station

Urban rail network of Amsterdam is an important public mass rapid transit system of the Netherlands. Lelylaan station is linking CBD and Schiphol Airport, which is located at green line (see Figure 5) and was operated in 1986. It is a typical urban rail station that here multimodal transfer is obvious that there are train, urban rail transit, tram, bus, P&R, B&R, K&R, taxi, etc. in this station area (see Figure 5). All transfer facilities are allocated compactly and kept in a 1000*500 $m^2$ plot.

![FIGURE 5 Urban rail network of Amsterdam (left) and satellite images of Lelylaan station (right)](image)

It is observed that there are two layers for all transit modes. Train tracks and urban rail tracks are arranged on elevated layer, and bus stops, tram stops, P&R, B&R, K&R are arranged on the ground layer. Here in this research, transfer between urban rail transit and bus, tram, P&R, B&R, K&R is considered.

- Urban rail transit: two-track, four-entrance, the length of stair from ground to elevate layer is 25m.
- Bus: U-shape lanes for bus to arrive, stop (four lanes) and depart (one lane), 6 bus lines (line 19, 62,63, 64, 95, 195), average departure frequency of bus $f_{bus}$ is 6min, average capacity per bus $q_{bus}$ is 30, bus transfer passenger flow volume is 10%.
- Tram: two-track, two-direction, two stops at one platform, average departure frequency of bus $f_{tram}$ is 10min.
- P&R: fee parking, 85 car parking lots totally, 30 of them under the elevated tracks, 55 of them in the open air, turnover ratio of car parking lots per day $\theta_{car}$ is 2,
utilization ratio of car parking lots per day $\rho_{\text{car}}$ is 90%, P&R transfer passenger flow volume $Q(\text{car})$ is 46 per day.

- B&R: 575 bicycle parking lots totally, 325 of them under the elevated tracks, 275 of them in the open air. Turnover ratio of bicycle parking lots per day $\theta_{\text{bike}}$ is 2, utilization ratio of bicycle parking lots per day $\rho_{\text{bike}}$ is 90%, and bicycle transfer flow volume $Q(\text{bike})$ is 1205.
- Taxi: 2 parking lots with information board, statistical number of taxi transfer per day $N(\text{taxi})$ is 3, average passenger capacity per taxi $q_{\text{taxi}}$ is 2.
- K&R: 1 parking lot with information board, statistical number of K&R transfer per day $N(kr)$ is 1.

Field observation of Lelylaan station was conducted, from which then we gained a plane figure of ground layer (see Figure 6). Based on the investigation results, transfer distance matrix of Lelylaan station is established (see Table 2). In the remainder of this section, we present the most interesting observations derived from the collected data.

### Transfer Coupling Degree Analysis at Lelylaan Station

#### Multimodal transfer coupling to urban rail transit

Bicycle transfer facilities are dispersed into four parts at station area, which are noted especially as BP1, BP2, BP3 and BP4. From matrix we could know the transfer distance matrix form BP to $M_i (i=1, 2, 3, 4)$. It is found that BP2, BP3, BP4 are much closer to M4, and BP1 is much closer to M1, that is, bicycle facilities concentrate in M4 and M1 more than M2 and M3. Passengers always would choose nearest entrance to enter or leave station. Therefore, in access transfer trip M4 and M1 could attract more bicycle transfer passenger flow to enter urban rail transit while M2 and M3 nearly seldom attract any. Comparatively speaking, passengers get out of the four entrances from platform is of much higher randomness. As a result, transfer walking distance would increase much in egress transfer trip. Figure 7 shows bicycle transfer routes to entrance (left is access transfer trip, right is egress transfer trip). In a word, it is necessary to design transfer facilities balanced relatively.

From Figure 7, it is clear to know that passenger’s transfer routes choose could be different in access and egress transfer trip. For example, in access transfer trip the routes include BP1→M1, BP2→M4, BP3→M4, and BP4→M4, and in egress transfer trip the routes should be M1→BP1, M1→BP2, M1→BP3, M1→BP4, M2→BP1, M2→BP2, M2→BP3, M2→BP4, M3→BP1, M3→BP2, M3→BP3, M3→BP4, M4→BP1, M4→BP2, M4→BP3, M4→BP4. According to transfer coupling model above, bicycle transfer coupling degree is calculated as follows:

$$C_{\text{tot}}(\text{bike}) = \frac{1}{2} \times \frac{1}{4} \times \sum_{j=1}^{2} \sum_{i=1}^{4} Z_{ij} \times N(\text{bike}) \times \theta_{\text{bike}} \times \rho_{\text{bike}} / Q(\text{bike})$$

$$= \frac{1}{2} \times \frac{1}{4} \times 8.47 \times 575 \times 90\% \times 2 / 1205 = 0.91$$
FIGURE 6 Plane figure of ground layer at Lelylaan station
| level | Matrix | modes | At-grade level | | | Ground Level |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Transfer | modes | Metro | Regional Train | Tram | Bus | Taxi | P&R | Bicycle | Car |
| | | | | | | | | | | | |
| AG level | metro | M1 | 0 144 162 209 | 27 145 181 258 | 139 157 | 318 323 | 261 37 | 18 241 271 300 | 250 |
| | | M2 | 145 0 35 111 | 145 30 106 183 | 5 30 | 220 225 | 163 181 | 162 143 173 202 | 152 |
| | | M3 | 162 35 0 124 | 184 106 30 147 | 30 5 | 233 238 | 176 199 | 180 156 186 215 | 165 |
| | | M4 | 209 111 124 0 | 231 153 117 35 | 106 119 | 109 114 | 52 246 | 227 32 62 91 | 41 |
| | train | T1 | 27 145 184 231 | 0 118 154 231 | 166 184 | 331 336 | 261 37 | 18 201 270 314 | 249 |
| | | T2 | 145 30 106 153 | 118 0 76 153 | 35 60 | 253 258 | 183 155 | 136 123 192 236 | 153 |
| | | T3 | 181 106 30 117 | 154 76 0 117 | 60 35 | 135 140 | 147 191 | 172 87 156 200 | 117 |
| | | T4 | 258 183 147 35 | 231 153 117 0 | 177 152 | 100 105 | 30 268 | 249 20 39 83 | 18 |
| G level | tram | P1 | 139 5 30 106 | 166 35 60 177 | 0 25 | 215 220 | 207 176 | 157 138 168 197 | 195 |
| | | P2 | 157 30 5 119 | 184 60 35 152 | 25 0 | 228 233 | 182 194 | 175 151 181 210 | 170 |
| | bus | B1 | 318 220 233 109 | 331 253 135 100 | 215 228 | 0 5 | 56 355 | 328 126 54 10 | 66 |
| | | B2 | 323 225 238 114 | 336 258 140 105 | 220 233 | 5 0 | 61 360 | 333 131 59 15 | 71 |
| | taxi | TP | 261 163 176 52 | 261 183 147 30 | 207 182 | 56 61 | 0 298 | 279 84 114 143 | 10 |
| | P&R | PR | 37 181 199 246 | 37 155 191 268 | 176 194 | 355 360 | 298 0 | 13 247 305 331 | 286 |
| | bicycle | BP1 | 18 162 180 227 | 18 136 172 249 | 157 175 | 328 333 | 279 13 | 0 234 292 318 | 267 |
| | | BP2 | 241 143 156 32 | 201 123 87 20 | 138 151 | 126 131 | 84 247 | 234 0 111 116 | 73 |
| | | BP3 | 271 173 186 62 | 270 192 156 39 | 168 181 | 54 59 | 114 305 | 292 111 0 | 44 | 10 |
| | | BP4 | 300 202 215 91 | 314 236 200 83 | 197 210 | 10 15 | 143 331 | 318 116 44 0 | 153 | 153 |
| | tempcar | TC | 250 152 165 41 | 249 153 117 18 | 195 170 | 66 71 | 10 286 | 267 73 10 153 | 0 |
It is found that bicycle transfer coupling to urban rail at Lelylaan station is in strength status (0.91). In the similar way, it is also calculated that bus transfer coupling degree is 0.796, P&R transfer coupling degree is 0.56, taxi transfer coupling degree is 0.189, K&R transfer coupling degree is 0.14, tramway transfer coupling degree is 0.61. Transfer routes choices in access transfer trip and egress transfer trip at urban rail station area are shown in Figure 8.

The types of transfer facilities at Lelylaan station are complete that urban rail transit could integrate with bus, tramway, bicycle, P&R, K&R and taxi, etc. very conveniently. From the results, it is clear to understand that B&R, bus transfer facilities have developed a tight coupling status to urban rail transit. By comparison, P&R and tramway transfer to urban rail transit is keeping in moderate coupling status because of lower transfer demand. In addition, weak coupling also exists at this station area, which taxi and K&R transfer facilities could supply a small number of transfers demand. Practice proved that the configuration of transfer facilities like these could satisfy transfers reasonably, from which we gain the experience that layering of transfer priority is quite important to design of transfer facilities according to transfer demand forecast or empirical investigation. Not all stations need such comprehensive transfer facilities as well. It is also proved that analysis of coupling status is not only a method for assessment but also a useful tool for planning and design.

Transfer facilities coupling status at different entrances

Totally there are 11 transfer facilities at station area, respectively are 4 B&R facilities, a pair of bus stops, 1 P&R facilities, a pair of tramway stops, 1 taxi boarding lot and 1 K&R parking lot. EWD of entrance to transfer facilities could be gained from transfer distance matrix (see Table 3). Coupling degrees for four entrances are calculated according to the model above, i.e. \( C(M_1) = 0.251 \), \( C(M_2) = 0.092 \), \( C(M_3) = 0.1 \), \( C(M_4) = 0.89 \). The results show that only transfer facilities around entrance \( M_4 \) is in tight coupling status, while those around entrances \( M_1, M_2, M_3 \) are in weak coupling status. Relatively \( M_1 \) is higher than \( M_2 \) and \( M_3 \). Obviously, if passengers choose transfer facilities around \( M_4 \), they could gain much more convenience both for short transfer walking distance and more kinds of transfer facilities.

It also shows that transfer facilities concentrate on one single entrance too excessively, which maybe is caused by land-use condition or planning ideas. It’s worth noting that facilities should be designed more balanced as long as land resource is adequate in order to shorten average transfer walking distance both in access transfer trip and in egress transfer trip.
B&R transfer routes to entrances

Bus transfer routes to entrances

P&R transfer routes to entrances

Taxi,K&R transfer routes to entrances

Tramway transfer routes to entrances

FIGURE 7 Transfer routes to entrance (left is access transfer trip, right is egress transfer trip)
Table 3 EWD of entrances to Transfer facilities (unit:m)

<table>
<thead>
<tr>
<th>j</th>
<th>EWD</th>
<th>BP1</th>
<th>BP2</th>
<th>BP3</th>
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CONCLUDING REMARKS

In this paper, we focus on the transfer coupling status of multimodal transfer facilities at urban rail stations. Transfer facilities of urban rail stations include bus stops (tramway stops), parking lots for P&R and B&R, taxi boarding area, etc. To this end, multimodal transfer system at urban rail stations is dissected regarding urban rail transit trip chain from origin to destination and multimodal modes in station area. Multimodal transfer coupling concept at urban rail station is put forward to analyze integration level problem, after which transfer coupling model is established, including transfer coupling degree for multimodal modes and different entrances. Field observation of urban rail station was conducted at Lelylaan station in the city of Amsterdam, and coupling status analysis derived from the collected data is discussed.

The main findings presented in this paper have a number of direct practical implications. First, multimodal transfer coupling concept is set up to research transfer integration problem. It makes bus, tramway, bicycle, car and taxi not only single transport modes but also effective transfer modes at urban rail station. Besides, transfer coupling development stages are introduced. This is a promising outlook for policy and station design planners aiming at increasing urban rail transit ridership.

Second, transfer distance matrix is proposed as a useful tool to show equivalent walking distance (EWD) between transfer facilities to urban rail transit, which we could understand types of transit facilities, location and number of all facilities and practical walking distance clearly during access transfer trip and egress transfer trip. In addition, design method of transfer distance matrix is also introduced in detail.

Third, transfer coupling models regarding coupling status have an effect on the way in which multimodal transfer modes integrate with urban rail station, and therefore should be used while planning and designing transfer facilities or assessing integration level of current layout. The models consider not only coupling relationship between urban rail transit to one kind of transfer modes, but also aggregation extent of transfer facilities at different entrances. It is found as well that coupling degree is not only related to transfer walking distance but also special features of B&R,P&R, bus, tramway, taxi, and K&R regarding transfer passenger flow, turnover ratio, utilization ratio, capacity of vehicles, etc.

Finally, an analysis of Lelylaan station in the city of Amsterdam is conducted to apply multimodal transfer coupling model. It is found that these concepts, ideas and models could have a reasonably good fit to practical case according to plane figure observation and transfer distance matrix. The types of transfer facilities at Lelylaan station are complete, with B&R and bus transfer facilities in a tight coupling status, P&R and tramway transfer in moderate coupling status, and taxi and K&R transfer facilities in weak coupling status. Also, it is found that transfer facilities concentrate on
one single entrance too excessively, which should be drawn attention of planners and
designers to avoid unbalanced status if resource is adequate. Therefore, future research
is recommended on how these findings and practical implications can be popularized
to practice for multimodal transfer at urban rail stations, and improving its effects step
by step.

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