1. INTRODUCTION

A public transport interchange is commonly understood to be the place where transfers between different public transport lines or modes occur. In large metropolitan areas few trips by public transport can be accomplished directly, without even a single transfer. Thus, using interchanges is an everyday experience for most city dwellers. Transfer at an interchange is usually associated with having to walk to a different stop or platform and time delay while waiting for the next connection. From the point of view of passengers, these two issues are the most important when evaluating the discomfort of transfer at a particular interchange.

An interchange consists of public transport stops and possibly also railway and/or metro stations as well as other facilities (e.g. Park and Ride car park, bicycle stands, kiosks, toilets, etc.). Public transport stop and station platforms are connected by walk links (pathways), which are also parts of an interchange. It should be noted that interchange definition used by Transport for London (2001) is more restrictive – the emphasis here is placed on the planned nature of interchanges: "Interchange facility – a purpose-built facility where interchange takes place, such as a railway station, bus station or bus/tram stop". As many public transport transfer areas in Warsaw arose spontaneously, without proper planning or design, the broader definition given in the first paragraph will be used in this paper.

It is commonly recognized that passenger friendly public transport interchanges play a key role in making public transport more attractive and more efficient. Yet besides general design guidelines and examples of good practice, there are no practical methods for assessing the level of friendliness, efficiency and service quality of interchanges. This paper presents an original method for evaluating public transport interchanges using 8 indicators as well as application of the method for assessing transport interchanges in Warsaw. All the indicators are quantitative and can be used for assessing both existing interchanges as well as plans for new or upgraded facilities.

2. BACKGROUND

The question how to plan and build good public transport interchanges has been arising interest in Europe for many years. The importance of the problem is evidenced by numerous projects financed by the EU, which have been attempting to develop universal guidelines and standards (e.g. projects: MIMIC, PIRATE, GUIDE, LINK, NICHES Plus). However, in the resulting literature (Terzis and Last, 2000; PIRATE, 2001; MIMIC, 2001; Mozos, 2003)
we can find descriptions of good practices and evaluation checklists rather than specific guidelines. So far, there seems to be no assessment method based on quantitative indicators.

One of the early attempts to provide some specific guidelines can be found in a book called: "A Pattern Language. Towns - Buildings - Construction" by Alexander et al. (1977). This classical textbook on shaping space by humans deals with public transport interchanges – among many others issues. The authors stress the importance of the role interchanges play in public transport systems. They claim that if transfers are not properly organized, the whole transport system will not be able to sustain itself. Therefore, interchanges should be treated as a priority in planning and organizing operation of public transport. Public transport lines and services should be planned in such a way that they connect points of interchange.

A more specific recommendation by Alexander et al. (1977) is that the distance needed to walk between two platforms in an interchange should not exceed 183 m. Maximum walking distance should become shorter as the trips become more local:
- 31 m when transferring from bus/tram to bus/tram,
- 61 m when transferring from mass rapid transit to bus/tram,
- 92 m when transferring from railway to mass rapid transit.

Further recommendation is that main connections between platforms should not cross any streets – “if necessary sink the roads or build bridges to make the transfer smooth”.

One of the working groups in the recently completed EU project "NICHES Plus" was concerned with "Passenger-friendly interchanges" (Monigl et al. 2011). Such an interchange should provide a short transfer path for passengers, safety and easy access and be an attractive public space. Potential benefits of passenger-friendly design include minimizing congestion and overcrowding, optimizing the location of key facilities, efficient use of space, increasing passenger satisfaction and increasing public transport modal share.

In the final documents of the Niches Plus project, it is recommended that the EC should finance a guide book on quality standards for interchanges to help cities, operators and authorities realise the concept more easily. The following desirable characteristics are given:

“Passenger-friendly interchanges:
- provide a great opportunity to use and be familiar with public transport modes for daily commuters, for tourists as well as for first time users;
- are safe, well-lit, clean;
- offer accessible, up-to-date information (e.g. timetable, smart guidance) where and when required;
- are basically designed to provide an accessible (easy to reach, easy to use) environment.”

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3. PROPOSED ASSESSMENT METHOD

There are over 40 locations in Warsaw where intensive transfers between public transport services take place and these are considered “public transport interchanges”. These interchanges involve a number of transport modes (railway, metro, tram and bus), facility types (multi-level stations, bus terminals, clusters of bus/tram stops) and a variety of passenger transfer conditions. With the aim of improving these conditions, the Roads and Public Transport Department of the City of Warsaw has recently commissioned two studies in which the authors of this paper took part.

In a 2010 study: “Analysis of organization and operation of transport interchanges in the City of Warsaw” (WYG International, 2010) an inventory of over 40 interchanges was carried out. The survey involved detailed mapping of each interchange, indentifying all platforms and pathways connecting them, recording public transport services and their frequencies as well as measuring walking distances and walking times between all platforms. As part of the study, authors of this paper proposed an assessment method which could be used for evaluating the design of new interchanges as well as the operation of existing ones. The proposed quantitative indicators address the following issues: (1) quality of basic infrastructure, (2) spatial integration of the interchange, (3) accessibility for the elderly and disabled persons, (4) ease of orientation, (5) personal security, (6) traffic safety, (7) passenger information, and (8) availability of additional facilities. Table 1 gives a brief description for each indicator.

Table 1 Description of quantitative indicators

<table>
<thead>
<tr>
<th>Id</th>
<th>Indicator name</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>W.1</td>
<td>Quality of basic infrastructure</td>
<td>Percentage of platforms and pathway segments meeting the basic quality standards</td>
</tr>
<tr>
<td>W.2</td>
<td>Spatial integration</td>
<td>Average walking distance and walking time between all platforms</td>
</tr>
<tr>
<td>W.3</td>
<td>Accessibility for the disabled</td>
<td>Percentage of platforms and pathway segments meeting the accessibility criteria</td>
</tr>
<tr>
<td>W.4</td>
<td>Ease of orientation</td>
<td>Average percentage of stops and station entrances visible from other platforms</td>
</tr>
<tr>
<td>W.5</td>
<td>Personal security</td>
<td>Percentage of platforms and pathway segments meeting the security requirements</td>
</tr>
<tr>
<td>W.6</td>
<td>Traffic safety</td>
<td>Average safety score for all pedestrian road crossings</td>
</tr>
<tr>
<td>W.7</td>
<td>Passenger information</td>
<td>Percentage of platforms and pathway segments meeting the information requirements</td>
</tr>
<tr>
<td>W.8</td>
<td>Additional facilities</td>
<td>Percentage of possible additional facilities actually provided</td>
</tr>
</tbody>
</table>

Most of the indicators in Table 1 represent the level of fulfilment of several preset criteria. For example, if out of 10 platforms at a certain interchange, 6 meet the personal security criteria (i.e. are well-lit and monitored by CCTV), then the degree of fulfilment is 60% and that is the value of the personal security indicator.
For determining values of indicators, the interchange needs to be first decomposed into basic infrastructure elements: platforms and pathway segments which should be uniform in character. It was assumed that pathway segments could be one of the following three types: footpaths, pedestrian crossings or stairs. Figure 1 shows these elements in a schematic representation of the Rondo de Gaulle’a Interchange. At this interchange, there are 2 tram stop platforms and 4 bus stop platforms. The platforms are connected with pathways comprising 5 footpath segments and 7 road crossing segments. As this is a single level interchange, there are no stairs.

Fig. 1 Example of schematic representation of interchange elements

The eight proposed indicators are described and explained below. The indicators were first proposed by the authors in 2011 (Krukowski et al., 2011) but were subsequently modified as more data were collected.

**W.1 Quality of basic infrastructure**

This indicator expresses the degree of compliance with building guidelines for public transport stops, issued by the Warsaw Public Transport Authority, as well as with the Building Code for public roads by the Ministry of Transport. The following basic criteria are considered: width of platform or pathway, length of bus/tram stop, surface evenness, lack of obstacles within the stop area, maximum kerb height, provision of shelter at the stop, etc. If any of these basic requirements is not satisfied, the whole element (i.e. platform or pathway segment), is deemed to be failing the quality test. The W.1 indicator is calculated as the percentage of elements which satisfy all the quality criteria.
W.2 Spatial integration
The proposed measures of interchange spatial integration (compactness) are average inter-platform walking distance and average walking time. To obtain a more accurate measure, the average walking distance should be calculated as the mean value weighted with passenger transfer flows. This is expressed by the following formula:

\[ \bar{d} = \sum_{i=1}^{n} \sum_{j=1}^{n} p_{ij} d_{ij} \]  

(1)

\( d_{ij} \) = distance between platforms i and j, measured along pathways,
\( p_{ij} \) = proportion of transfers between platforms i and j, i.e. ratio of the number of passengers transferring between platforms i and j to the total number of transfers at the interchange,
\( n \) = number of active platforms at the interchange.

The most convenient transfers occur on the same platform. However, the walking distance in such cases is not zero as some walking along the platform is usually involved. It is assumed that same-platform transfer distances are equal to 1/3 of the platform length.

The average transfer walking time is calculated using a formula similar to (1) but with walking times \( t_{ij} \) substituted for distances. The problem with using formula (1) is that it requires knowledge of passenger transfer flows at the interchange. A simpler way to assess spatial integration is to calculate the mean inter-platform distance as:

\[ \bar{d}^2 = \frac{2}{n(n+1)-2K} \sum_{i=1}^{n} \sum_{j=1}^{n} d_{ij} \]  

(2)

\( K \) = number of platforms where transfers within the same platform do not occur (e.g. a platform for alighting only); for these cases we should assume \( d_{ii} = 0 \).

W.3 Accessibility for the elderly and disabled persons
This indicator expresses compliance with accessibility requirements such as: provision of ramps or lifts wherever stairs occur at the interchange, provision of railings along ramps, tactile warning surfaces along platforms and before stairs, lowered kerbs and tactile surfaces at pedestrian road crossings, contrast marking of platform edges, audible traffic signals, etc. The W.3 indicator is calculated as the percentage of elements (platforms, pathway segments) which satisfy all the accessibility requirements.

W.4 Ease of orientation
This indicator is based on visibility of bus/tram stop signposts from each other. For platforms located at a different level, marked entrance to the station or underground/overhead pathway is taken instead of the stop signpost.
number of stops or entrances visible from each stop is counted first and then the average calculated. The W.4 indicator is that average number divided by (n-1) and expressed as a percentage.

W.5 Personal security
The basic criteria for personal security are: adequate lighting and provision of CCTV monitoring. The W.5 indicator is calculated as the percentage of elements (platforms, pathway segments) which satisfy both of these security requirements.

W.6 Traffic safety
This indicator concerns road crossings only and expresses average safety score representing the “degree of safety”. The degree of safety is assigned to each road crossing depending on its type as follows:

- underground or overhead crossing = 100%
- signalised crossing, no conflicts with turning vehicles = 70%,
- signalised crossing, conflicts with turning vehicles = 50%,
- unsignalised zebra crossing = 30%
- unmarked pedestrian crossing = 0%

W.7 Passenger information
The criteria of adequate information are: provision of timetable and fare tariff at each stop, plan of the interchange and surrounding area, plan of public transport network, directional signage at platforms and pathway nodes. The W.7 indicator is calculated as the percentage of elements (platforms, footpaths) which satisfy all of these requirements.

W.8 Availability of additional facilities
Additional facilities and services include: covered platforms and pathways, benches, dustbins, ticketing machines, shops, toilets, taxi stand, bicycle stands, car parks. The W.8 indicator is calculated as the percentage of potential facilities actually provided.

4. METHOD APPLICATION

4.1 Study of 10 interchanges
In the second study conducted in 2011 (Transplan Konsulting, 2011), the above assessment method was applied for evaluating 10 public transport interchanges in Warsaw. Interchanges selected for the study were varied in character and could be considered as representative of all the others. Table 2 shows the main characteristics of the 10 interchanges: number of platforms, number of levels, public transport modes present and interchange location.

Two methods of field data collection were used: passenger counting with interviews (“full survey” indicated in Table 2) and interchange audit. Four interchanges were surveyed using the passenger interview method which involved counting passengers boarding and alighting public transport vehicles as well as interviewing passengers waiting at all platforms within the
interchange.

Table 2  Characteristics of the assessed interchanges

<table>
<thead>
<tr>
<th>Interchange name</th>
<th>Number of platforms</th>
<th>Number of levels</th>
<th>Modes*</th>
<th>Location</th>
<th>Survey conducted</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bemowo Ratusz</td>
<td>5</td>
<td>1</td>
<td>B, T</td>
<td>peripheral</td>
<td>full</td>
</tr>
<tr>
<td>Rondo de Gaulle’a</td>
<td>6</td>
<td>1</td>
<td>B, T</td>
<td>central</td>
<td>full</td>
</tr>
<tr>
<td>PKP Rembertów</td>
<td>6</td>
<td>2</td>
<td>B, R</td>
<td>peripheral</td>
<td>audit</td>
</tr>
<tr>
<td>PKP Włochy</td>
<td>6</td>
<td>2</td>
<td>B, R</td>
<td>peripheral</td>
<td>audit</td>
</tr>
<tr>
<td>Metro Świętokrzyska</td>
<td>7</td>
<td>3</td>
<td>B, T, M</td>
<td>central</td>
<td>audit</td>
</tr>
<tr>
<td>Rondo Waszyngtona</td>
<td>9</td>
<td>2</td>
<td>B, T</td>
<td>central</td>
<td>audit</td>
</tr>
<tr>
<td>Plac Zawiszy</td>
<td>17</td>
<td>2</td>
<td>B, T, R</td>
<td>central</td>
<td>audit</td>
</tr>
<tr>
<td>Metro Wilanowska</td>
<td>17</td>
<td>3</td>
<td>B, T, M</td>
<td>peripheral</td>
<td>full</td>
</tr>
<tr>
<td>Metro Młociny</td>
<td>17</td>
<td>3</td>
<td>B, T, M</td>
<td>peripheral</td>
<td>audit</td>
</tr>
<tr>
<td>Metro Marymont</td>
<td>21</td>
<td>3</td>
<td>B, T, M</td>
<td>peripheral</td>
<td>full</td>
</tr>
</tbody>
</table>

* B = bus, T = tram, M = metro, R = suburban railway

4.2 Results of interview survey

Interviews were conducted during the morning and afternoon peak periods (3 hours in each peak). Key questions of the interview were whether the passenger was transferring at that interchange and if so between which platforms. Question about the comfort of walking during transfer was also included and some passenger details captured (gender, age group). On average, around 20% of boarding passengers were interviewed and the data obtained were used to estimate the matrix of transfer movements within the interchange. Figure 2 shows the estimated pattern of transfers at Rondo de Gaulle’a Interchange during the morning peak. It can be seen that the heaviest transfer flows are between trams running East-West and buses running North-South.
Fig. 2 Passenger transfer flows at Rondo de Gaulle’a Interchange (7-10 am)
Passenger traffic at the busiest interchange (Metro Wilanowska) was close to 17 thousand persons boarding during the morning 3-hour peak and over 17 thousand persons during the afternoon peak. The second busiest interchange was Metro Marymont, with about 14 thousand passengers during the 3-hour peaks. At all the 4 interchanges where interviews were conducted, a high percentage of transfer passengers (70-80%) was observed.

Given the information about transfer flows, it was possible to calculate the spatial integration indicators using formulas (1) and (2). Inter-platform walking distances and times captured in the interchange inventory study were used for that purpose. Comparison of W.2 indicator values for the 4 interchanges where full survey was carried out is shown in Fig. 3. The average inter-platform walking distance ranges from 136 m to 327 m and the average walking time between platforms from 1.87 to 3.27 minutes. These values suggest that the Warsaw interchanges are generally not very well integrated. The level of integration decreases with interchange size, measured for example by the number of platforms. A comparison of results obtained using the flow-weighted average (formula 1) and simple average distance (formula 2) shows that simple average formula seems to underestimate the true mean value for smaller interchanges and overestimate it for large interchanges.
During the interview passengers were asked to rate the walking comfort on a 5-point scale as: very uncomfortable, uncomfortable, acceptable, comfortable, very comfortable. Despite rather long walking distances needed for transfers, passenger opinions about transfer comfort were surprisingly positive. The percentage of respondents giving positive comfort rating (comfortable + very comfortable) was 61% at Rondo de Gaulle’a, 74% at Metro Wilanowska and 68% at Metro Marymont. Thus, the percentage of ‘satisfied’ passengers does not decrease with increasing average walking distance. This shows that passengers in Warsaw are used to long walking during transfers and accept it as normal.

4.3 Results of interchange audit

During the second stage of the survey, all ten interchanges under study were audited using special checklist forms. These were prepared separately for different infrastructure elements: stop/station platforms, footpaths, stairs and pedestrian road crossings. A schematic representation (e.g. Figure 1) was prepared for each interchange, identifying the platforms and pathway segments of different type. For each of the seven indicators (W.1 and W.3 to W.8) several checklist criteria were used, corresponding to the items listed in section 2.

At the data processing stage, the percentage of infrastructure components meeting the criteria for each indicator was calculated. To illustrate the method, Table 3 shows sample calculations for Rondo de Gaulle’a interchange. For example, the value of W.1 indicator is 50%, as 9 elements (2 platforms + 7 pathway segments) out of the total of 18 elements (6 platforms + 12 segments) meet the infrastructure quality criteria.
Table 4 shows the values of indicators obtained for all ten interchanges under study plus the average values. Indicators with the lowest average values are concerned with accessibility (21%) and information provision (24%). Mid-range average values were obtained for basic infrastructure quality, traffic safety and ease of orientation. Personal security indicator has the highest average value (74%). Comparison of indicators calculated for the ten interchanges shows that indicator values generally depend on interchange age – recently built or modernised interchanges scored better than the older ones. The best overall results were obtained for the recently completed Metro Młociny interchange. Although it has some drawbacks, this interchange was purposely designed and built as the major suburban transfer point at the terminal station of the first metro line.

Figure 4 presents values of six indicators (excluding W.2 and W.8) for the four interchanges where full surveys were conducted. This graphical representation confirms conclusions presented above: generally good results of the personal security indicator and poor results in the areas of accessibility and information provision.

Table 4 Values of the assessment indicators for all 10 interchanges

<table>
<thead>
<tr>
<th>Interchange name</th>
<th>Infrastr. quality %</th>
<th>Integration</th>
<th>Accessibility %</th>
<th>Orientation %</th>
<th>Security %</th>
<th>Safety %</th>
<th>Information %</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bemowo Ratusz</td>
<td>69</td>
<td>136</td>
<td>0</td>
<td>100</td>
<td>63</td>
<td>50</td>
<td>20</td>
</tr>
<tr>
<td>Rondo de Gaulle’a</td>
<td>50</td>
<td>168</td>
<td>31</td>
<td>43</td>
<td>89</td>
<td>49</td>
<td>18</td>
</tr>
<tr>
<td>PKP Rembertów</td>
<td>65</td>
<td>193</td>
<td>20</td>
<td>40</td>
<td>43</td>
<td>31</td>
<td>20</td>
</tr>
<tr>
<td>PKP Włochy</td>
<td>26</td>
<td>191</td>
<td>20</td>
<td>40</td>
<td>65</td>
<td>53</td>
<td>18</td>
</tr>
<tr>
<td>Metro Świętokrzyska</td>
<td>35</td>
<td>237</td>
<td>18</td>
<td>76</td>
<td>77</td>
<td>70</td>
<td>38</td>
</tr>
<tr>
<td>Rondo Waszyngtona</td>
<td>78</td>
<td>150</td>
<td>0</td>
<td>83</td>
<td>33</td>
<td>85</td>
<td>0</td>
</tr>
<tr>
<td>Plac Zawiszy</td>
<td>24</td>
<td>200</td>
<td>9</td>
<td>37</td>
<td>96</td>
<td>59</td>
<td>25</td>
</tr>
<tr>
<td>Metro Wilanowska</td>
<td>69</td>
<td>237</td>
<td>33</td>
<td>63</td>
<td>82</td>
<td>42</td>
<td>14</td>
</tr>
<tr>
<td>Metro Młociny</td>
<td>69</td>
<td>202</td>
<td>58</td>
<td>66</td>
<td>100</td>
<td>48</td>
<td>40</td>
</tr>
<tr>
<td>Metro Marymont</td>
<td>52</td>
<td>327</td>
<td>16</td>
<td>37</td>
<td>93</td>
<td>56</td>
<td>46</td>
</tr>
<tr>
<td>Average</td>
<td>54</td>
<td>204</td>
<td>21</td>
<td>59</td>
<td>74</td>
<td>54</td>
<td>24</td>
</tr>
</tbody>
</table>
5. CONCLUSIONS
The assessment shows that the Warsaw interchanges are generally not very well integrated, with the average inter-platform distance ranging from 136 m to 327 m and the average walking time between platforms from 1.87 to 3.27 minutes. The level of integration decreases with interchange size, measured for example by the number of platforms. Values of the other seven indicators generally depended on interchange age – recently built or modernised interchanges scored better than the older ones.

Assessment results can now be used for preparing plans for upgrading those interchanges where the biggest problems have been identified. Low values of some indicators (e.g. in the area of information and accessibility for the disabled) suggest the opportunity for low-cost improvements of the interchange level of passenger friendliness. It is hoped that these improvements can to some extent compensate for the shortcomings of infrastructure.

Bibliography


