Traffic Planning Concerning Pedestrian Traffic in Cities

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Abstract. The aim of the paper is to familiarize readers with the issue of planning and modelling the urban pedestrian traffic. The introduction describes the factors that must be taken into account before designing new pedestrian roads or during reconstructing existing pedestrian areas. The paper furthermore introduces levels of quality of movement of pedestrian traffic, individual types and categories of pedestrians, including their own traffic behaviour. The final part of the paper summarizes the various approaches to addressing this issue, including the presentation of the possibilities of pedestrian traffic modelling based on computer simulation.

1. Introduction

Pedestrian traffic is considered to be a natural part of non-motorized transport and its frequency is particularly noticeable in built-up areas in cities, villages or places where human efforts are concentrated. It is in such built-up areas where short-distance trips mostly occur. Along with another type of non-motorized transport, which is cycling, pedestrian traffic is one of the ecological modes of transport. Compared to motor transport, they are characterized mainly by smaller space requirements and by not harming the environment.

In the Czech Republic, the standardization of pedestrian roads and their parameters are mainly dealt with in the Czech technical standard ČSN 73 6110 - designing local roads. This regulation deals directly with the design of urban local roads, which is applicable to both motor and non-motorized transport, and classifies them into several categories (functional groups). Generally, urban pedestrian traffic uses roads of the functional group D, which is further divided into two subgroups designated D1 and D2. Subgroup D1 defines the terms “pedestrian zone” and “residential zone”, which are actually local roads with mixed traffic of both motor and non-motorized transport with given rules. Subgroup D2 refers to roads for non-motorized transport that are fully segregated from other modes of transport (especially pedestrian and cycle paths, pavements, underpasses, overpasses, etc.). In built-up areas, these roads are in most cases part of the so-called associated traffic area of roads of function groups B and C (collection and service local roads), and in the non-urban areas, they refer to roadsides or pedestrian paths. However, pedestrian roads very often crossroads for motor transport, unless we are talking about pedestrian or residential areas where pedestrians can legally move along the entire width of the road. In the event of increased demand for crossing, pedestrian crossings or crossing points shall be established, in particular on roads with traffic volume of more than 5 000 vehicles/24 h in both directions of travel [1].
In addition to the movement of pedestrians in certain zones, their residential function must also be taken into account. A pedestrian belt in the associated traffic area creates a walk-through space, so it must be spatially dimensioned according to the parameters contained in the standard. The width of the pedestrian belt must match the intensity of the pedestrian traffic and the nature of the road; together with the safety distances, it forms the width of the pavement. In relation to the associated road, pedestrian safety is taken into account in particular. For this reason, various safety and calming measures are applied on the roads, such as reducing the speed of traffic flow and checking compliance with it, segmenting pedestrian traffic from motor traffic by means of vegetation (alleys, green belts), railings, central dividing islands, etc. [1].

2. The level of quality of pedestrian movement in cities
Standard [1] further defines the level of quality of pedestrian movement, which is conceptually similar to the level of traffic quality (level A - F) and expresses the relationships between walking speed, volume and density of pedestrian flow. Generally, it expresses a kind of walking comfort for people. Not only on the basis of this level of pedestrian movement quality, it is determined that, in order for the movement of the various groups of pedestrians on pavements to be as comfortable as possible, the width of the pavement must be at least 1.50 m (without safety distance). The minimum width of the pavement is generally 0.75 m, which corresponds to one lane for pedestrian flow in one direction, but there is no guaranteed pedestrian comfort in the form of pedestrian overtaking, walking at a certain speed, etc. Completely different widths apply to pedestrian paths [1].

The performance of pedestrian roads can also be determined on the basis of the quality level of pedestrian movement set by Standard [1]. Considering a lane for a flow of pedestrians in one direction corresponding to a width of 0.75 m, the performance of the first and second lane in the two-lane pedestrian belt is approximately 900 pedestrians/hour (considering the quality of pedestrian movement on the level C). Table 1, contained in [1], illustrates the approximate performance of pedestrian roads in relation to the quality level of pedestrian movement.

| Quality level | Average pedestrian density/m² | Average speed km/h | Pedestrian performance h/lane | Characteristics |
|---------------|-------------------------------|--------------------|-------------------------------|-----------------|
| A             | 0.08                          | 12                 | 4.8                           | 120 - 180       |
|               |                               |                    |                               | The pedestrian moves freely, at the selected speed, without conflicts |
| B             | 0.27                          | 3.7                | 4.6                           | 240 - 360       |
|               |                               |                    |                               | The movement is still free, the influence of the presence of other pedestrians is small |
| C             | 0.45                          | 2.2                | 4.4                           | 600 - 900       |
|               |                               |                    |                               | Possibility of walking at normal speed as well as overtaking in one direction, minor conflicts in the cross and opposite movements, a slight speed reduction |
| D             | 0.71                          | 1.4                | 4.1                           | 900 - 1300      |
|               |                               |                    |                               | Choice of speed and overtaking is limited, cross and opposite movements require changes in speed and position and are conflicting, noticeable interactions between pedestrians |
| E             | 1.67                          | 0.6                | 2.7                           | 1500 - 2200     |
|               |                               |                    |                               | Significant speed limitations, overtaking is not possible, cross and opposite movements with great difficulty, capacity limit state with interruption or stopping of the movement |
| F             | > 1.7                         | < 6                | variable                      | Movement is unstable and possible only by shifting, constant contact with other pedestrians, cross and opposite movements are excluded, the conditions similar to a cluster of pedestrians without movement |

Table 1. Pedestrian road performance in relation to a quality level [1]
Various factors affecting the quality of pedestrian movement are taken into account in the planning of pedestrian belts. Level A expresses a condition where a pedestrian is moving at a freely selected speed without conflicts, no factors preventing their natural walking. Level F, on the other hand, expresses a situation where pedestrian movement is unstable, only possible by shifting and with constant contact with other pedestrians. One of the basic factors influencing this is the width of the pavement, the speed of pedestrian flow resulting from the slowest participant of traffic in a row, obstacles on the street such as lampposts, pedestrian volume and related pedestrian traffic density, pedestrian congestion level in front of various objects (public transport stops, pedestrian crossings), pavement slope, etc.

3. Types and categories of pedestrians

Basically, the speed of walking is divided into three categories: the fastest - youth, students; slower - walking to work; the slowest - shoppers, persons with reduced mobility. The speed difference between the two extreme groups is about 30 % [1]. An interesting view of the division of pedestrian groups is provided by the international grouping in the form of the charter “Walk21”, which seeks to create favourable conditions for pedestrians in the urban areas worldwide. The individual categories of pedestrians have specificities that must be taken into account when planning. Pedestrians are a diverse group of road users with characteristics that reflect the diversity of the general population [2].

| Type of pedestrian | Subcategory |
|--------------------|-------------|
| Walking            | Proficient walker |
|                    | Runner |
|                    | Adult pedestrian |
|                    | Young pedestrian |
|                    | Pedestrians with impaired walking ability |
|                    | The elderly |
|                    | Pedestrians with a guide dog |
|                    | Pedestrians with impaired orientation ability |
|                    | Pedestrians with a stick |
|                    | In-line skaters |
|                    | Roller skaters |
| Using wheels       | Skateboarders |
|                    | Scooter riders |
|                    | Pedestrians with prams |
|                    | Pedestrians in a wheelchair with a manual drive |
| With reduced mobility | Pedestrians in an electric wheelchair |
|                    | Pedestrians with a walker |
|                    | Pedestrians on scooter |

Various specialized traffic surveys and subsequent planning are carried out to determine the current state of pedestrian traffic (in particular traffic volumes on pedestrian belts or pedestrian crossings). The methodology contained in Technical Conditions no. 189 (TP189) is used to determine the volumes of pedestrian traffic from a short-term survey. Based on the number of pedestrians in the profile of a pedestrian road obtained during a traffic survey (at least 4 hours during peak hours on a normal working day), a theoretical estimate of the day-to-day pedestrian traffic volume on a given road can be established. The calculation is carried out using conversion coefficients, which were obtained from a long-term traffic survey on the basis of statistical methods, according to a simple relationship [3]:

\[ I_d = I_m \times k_{m,d} \text{[p/24 h]}, \]

where:
$I_d$ daily pedestrian traffic volume on the day of the survey [p/24 h];

$I_m$ pedestrian traffic volume at survey time [p/survey time];

$K_{m,d}$ conversion coefficient of traffic volume during the survey time to the daily volume of pedestrian traffic on the day of the survey (considering variations of volumes in pedestrian traffic during the day) [-].

Conversion coefficients values $K_{m,d}$ are gained from the tables given in the appendix of TP189 and contain the percentage of hourly volumes on the all-day volume. The values of conversion coefficients $k_{m,d}$ for any survey time chosen are calculated using the following relationship [3]:

$$K_{m,d} = \frac{100 \%}{\sum p_i^d} [-],$$  \hspace{1cm} (2)

where:

$p_i^d$ is the sum of the ratios of the hourly traffic volumes over the survey period in the daily traffic volume [%].

Methodology [3] also lays down the rules and other requirements for carrying out a pedestrian traffic survey. In particular, the times (preferably between 1:00 p.m. and 5:00 p.m. on a normal working day) and the period of conducting the traffic survey, but also the need to conduct the survey in favourable weather conditions. However, if the survey was conducted under inappropriate weather conditions, the survey results can be professionally updated (increased).

4. Monitoring of traffic behaviour of inhabitants

Surveys are carried out among the residents of the territory in order to create models where transport processes can be simulated and scenarios determined and to obtain a statistical sample (to determine the pattern of traffic behaviour). Nowadays, this monitoring of the traffic behaviour of inhabitants is an effective and efficient tool for transport planning in territorial units. The beginning of analytical work on a comprehensive sample of inhabitants' traffic behaviour data dates back to the 1930s when Liepmann in [4] analysed data on the trips of workers in England in the 1930s. In fact, many current topics and concepts were described by Liepmann in his work; by analysing data, for example, he monitored the time spent travelling to work, ride-share, etc. Since the 1950s, monitoring the traffic behaviour of the population has become increasingly topical among a scientific community as the possibilities for transport mode selection, acceleration of transport, use of road vehicles etc. have grown. In the 1970s, the International Association for Travel Behavior Research was established. However, the data collected for the purposes of traffic planning were also used for analyses in other fields such as economics, regional development, socio-demographic sciences, etc. Torsten Hagerstrand in [5] developed a time-space prism and fundamentally influenced behavioural geography: the structure of the region is shaped by the regularity of the steps of individual actors in space and time. Mode choice analysis by Ben-Akiva and Lerman in [6] contributed to a better understanding of the traffic behaviour of inhabitants. Another scientific study by Kockelman [7] was focused on the determination and quantification of the influence of territory on the traffic behaviour of the inhabitants. Although this is not a comprehensive list of studies on travel (traffic) behaviour, it demonstrates the diversity of disciplines that use population behaviour data.

In particular, national surveys (e.g. national censuses) or various projects using a “travel journal” represent the basic tools for collecting data on traffic behaviour of the population. The respondents
cooperate voluntarily by writing down regularly monitored data. The aim of the journal is to obtain
from the respondents (volunteers) data mainly on what they use as a means of transport in a given time
period, how often they travel (periodicity), how long their journey lasts, where they travel and for
what purpose, what the costs of their travels are, etc. Nowadays, there are new trends that should be
recorded by means of these journals, such as car sharing or ride-sharing with co-workers or family, the
use of vehicles with alternative types of propulsion, or even the use of autonomous vehicles.

Today, with the advancement of communication technologies, the journals (and data collection)
can be automated or even technologically developed. With the help of applications in mobile phones,
the respondents can even be monitored (voluntarily) during their journeys by means of GPS, whereby
a record of their movement is obtained. The user then fills in other important information about their
trip [8].

In Germany, a “mobility panel” at Karlsruhe Institute of Technology has been operating for
twenty-five years to study the traffic behaviour of inhabitants, changes in time, and to come up with
proposals for the sustainable development of transport and transport infrastructure. The data collection
is also based largely on travel journals along with other questionnaire surveys. Reports are regularly
published, where extensive statistical data are analysed clearly.

4.1. Possibilities of modelling of pedestrian traffic
In addition to the monitoring of traffic behaviour of inhabitants, analysts and researchers also focus on
studying pedestrian traffic and modelling its characteristics. Compared to the modelling of e.g.
individual automobile transport, which is mostly tied to roads, the approach is somewhat more
complicated in the modelling of pedestrian traffic on transport infrastructure. Moreover, psychological
factors and human behaviour play a major role here. In general, pedestrian traffic models are geared
towards crowds in two-dimensional space [9].

With the help of various techniques in both macroscopic and microscopic environments, many
studies have been made on this subject. For example, Banerjee in his work [9] looked at the
determination of both pedestrian flow characteristics (e.g. speed, volume, density, etc.) and the level of
quality of traffic on various pedestrian traffic facilities (escalators, stationary stairs, pavements in
various inclinations, pedestrian paths etc.). Other models based mainly on destination or route
selection in urban areas are dealt with by Oyama and Hato in [10]. In their work, Zhu and
Timmermans [11] follow the links between route selection and the purpose of trips. As can be seen
from the above, there have been a several authors with different approaches to designing pedestrian
traffic models that assist in modelling future volumes and transport relationships in cities.

5. Conclusion
As mentioned in the paper, various factors influence the quality of pedestrian movement when
planning and modelling pedestrian traffic in cities. These factors must be taken into account before
designing new pedestrian roads or during reconstructing existing areas. The calculation of the capacity
of these areas includes not only the required level of quality of pedestrian traffic but also types and
categories of pedestrians and their own traffic behaviour. The paper briefly described various
approaches to addressing this issue, including the introduction of pedestrian traffic modelling
possibilities based on computer simulation. However, given the positives and environmental benefits
that this kind of non-motorized transport subsequently brings to its region, it pays to invest in its
preparation and detailed planning.
Acknowledgment(s)
This manuscript was supported within solving the research project entitled “Safe and secure cities for pedestrians and senior citizens” of the ÉTA programme of the Technology Agency of the Czech Republic, project no. TL02000559.

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