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Regularities of Pedestrian Flows Formation in Residential Areas of Cities

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Abstract

Currently in urban planning practice, as in new construction and at reconstruction, paid not enough attention to pedestrian flows movement, thereby reducing the usability pedestrian communications like one of the indicators to measure the efficiency of the transport system. This article describes the specific features points of generation and absorption pedestrian flows. The main purpose of research is to determine the quality of service on the pedestrian lanes on the basis of the developed model of pedestrian correspondence in a residential area of large and major cities. The statistical analysis of generation and absorption of pedestrian traffic of gravity points are made on Kharkiv sleeping district example. Obtained results is simulating model of gravity allows to describe the real life situation and create the matrix of pedestrian correspondence in city's sleeping areas. As a result of the imposition of correspondence received on sections of the road network it has been possible to determine the values of pedestrian traffic parameters. These parameters are allowed to carry out an analysis to determine the level of pedestrians service. The research results can be applied by experts during design of residential areas, or in placement of new facilities gravity pedestrian flows in the existing building.

Keywords

Pedestrian Flow, Transportation, Correspondence, LOS

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1. Introduction

Transportation of population connected with its manufacturing, cultural and social needs that are made by feet, public or individual transport. In a majority, transportations of people are regular through time and they have relative space-time stability.

Transportation of people in the city can divide on the transportation inside the buildings (intercommunications) and transportation outside the buildings, (external communications). Intercommunications use for calculation of evacuation time in case of building design and for communication paths geometry features [1, 2].

It is necessary to pay attention on external transportation in the context of municipal transport systems functioning.

Foot traffic is the widespread kind of people transportation on the city. Besides, it is essential part of total time transportation (30%) [3].

We can classify foot traffic types with the help of next characteristics [4]:

- Quantity of road users;
- Flow streamline;
- Structure of flow;
- Duration of transportation process;
- Conditions of transportation (normal, accident).

You may see foot traffic classifications in Ukrainian and

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European countries on figure 1-2.

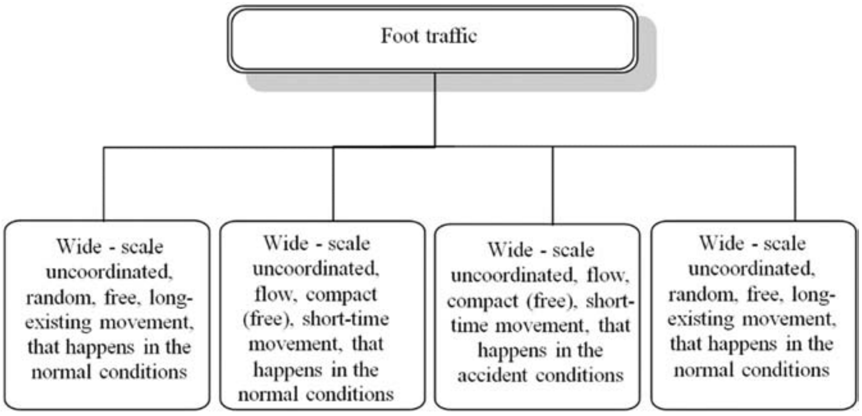

Figure 1. Homelands foot traffic classification.

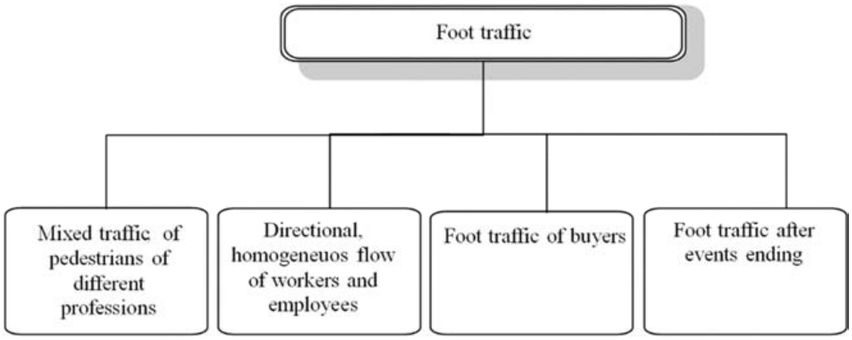

Figure 2. Europeans foot traffic classification.

Comparing above-mentioned classifications, we can note that they are similar to each other but homeland classification is wider because it includes accident conditions. Foreign classification is more acceptable for consideration of foot traffic in normal conditions. In our research we will not be describe accident situations.

Depends on destination, the pedestrian movements can be divided into working and cultural-social transportations. Movements that form on the ways to enterprises, institutions and attraction points belong to working transportations. They characterize by homogeneity and orientation. It is current, mass-wide movement, which takes place in normal conditions. It includes movement of students and scholars too.

The movement of human flows with their cultural and social aims are characterized by flow inhomogeneity depends on its direction and road users. Cultural and social movements can be both long existing, contrary and unilateral short time (the movement of human flows after the events ending).

Foot traffics direct to the attraction points (means the places of formation and absorption of pedestrian communications) such as: residential buildings, stops of public transport, car parks, organizations and institutions, objects of cultural and social services, and more.

Buildings can be divided into groups depends on generation characteristics of foot traffic [4, 5]:

- Spectacular type that is episodic or cyclic;
- Commercial type, which is continuous in the course of the day, with increasing of volume in evening "peak- hour";
- Industrial, administrative, educational, residential, type that characterize by strongly pronounced morning and evening "peak-hour" periods;
- Passenger transport type that works according to transport working schedule and it depends on the surrounding buildings.

The one of the main characteristics for attraction point objects is the factor of transport and foot availability. The allocation of social and service objects hold on according to regulations [4, 5]: for enterprises and institutions, that serve the population everyday 150-500 м (2-6 min), occasionally – 500-1000 м (8-15 min), from time to time – more 1500 м (more than 20 min).

According to [6], the of foot availability range of municipal transport stops is 500 м. The author of work [7] suggests us to use test method of foot availability range of municipal transport stops in big, large and wide cities. This method takes into account the unstraightness of footpath, the quantity of municipal passenger transport routes and headway. Thus, the author of this work proves the influence of quantity route and average network domain of transport movement on the foot availability of municipal transport stops. Foot availability of shop is specified distance from shop to the center of uptown that provides the rational distribution of retail trade network [8]. Practically, we can see 3 trade areas which are defined by buyers availability principles such as: the closer one (10-12 min of foot availability), average (12-20 min of foot availability) and long-distance (more then 20 min) [8]. According to building standards [6], for trade enterprises, food service and social service the foot availability range is 500m in multistory building (6 min if the speed of pedestrian is 5km/h).

Review of literature sources showed that studied flow creating and absorbing characteristics of buildings are not enough studied in this way. In [4, 5] we can see the dependencies of daily generate capacity of foot traffic buildings that depend on their technical and operational characteristics. These dependencies are enough inexact and they did not specify during last years. In general, they use for calculation of evacuation ways and foot areas near buildings.

2. Pedestrian Traffic Model Design

Foot traffic flows model is the tool for calculation and forecast of functional network parameters. Here we can refer intension, density and foot traffic specific intensity.

Foot traffic density is the quantity of people on the footpath unit area. (Footpath means pavement, pedestrian road, underground and aboveground crossover).

$$q = Q / F , \quad (1)$$

where q is foot traffic density, people./m^2;

Q – quantity of people, which locate at a particular segment of the road network, people;

F – footpath area, m^2.

The common footpath load characterizes by the foot traffic intensity (N). It defines the quantity of pedestrian that pass through the footpath cross section in the time unit (one hour):

$$N = Q / t , \quad (2)$$

where N – foot traffic intensity, people/hour;

t – calculation period, hour.

Calculated characteristic is the movement specific intensity:

$$n = \frac{N}{b} . \quad (3)$$

Footpath overall width, m.

To solve the problem of construction the pedestrian traffic model we can choose several stages (Table 1).

Table 1. Stages of design the distribution model of foot communication in the network.

Stage	Tasks
1. Network description	1.1 Design the topological diagram 1.2 Description the ways of communication 1.3 Determination the generation and absorbing volume of foot flows.
2. Model design	2.1 Calculation of the shortest distancies 2.2 Calculation of communication 2.3 Calculation of foot flows distribution in the network.
3. Models check	3.1 Experimental research of foot flows parameters. 3.2 Validity check of foot flow distribution model in the network. 3.3 Model calibration

Design the topological diagram

The topological method is most appropriate for model configuration description.

The network describes here graphically [9]. All the communication ways are given in the form of ordered set sections. Network nodes are crossing of communication routes and foot attraction points. Arcs are space interval between nodes.

Description of communication ways.

Communication ways are characterized with the huge amount of parameters: route plan, centerline grade, type of surface, and path length. Natural method is the most appropriate to define communication ways characteristics [4, 10]. Configuration and path length it is better to define with the help of ground maps.

Determination the generation and absorbing volume of foot flows.

Foot flows direct to the attraction point objects, places of appearing and absorbing foot communications (residence buildings, municipal transport stops, parking, organizations and institutions, cultural and social service objects etc.)

With the help of natural researching method, it is possible to receive the information about generation and absorbing volume of foot flows [4, 5, 11]. The point of this method is that researchers make a calculation of generation and absorbing volume of foot flows in the different network nodes. This method gives us more accurate results cause there are no assumptions, but it is characterized by significant labor costs. However, this method is the most appropriate for receiving the information about generation and absorbing volume of foot flows.

Calculation of the shortest distances.

There are several methods to calculate the shortest distances nowadays. The most famous and frequently used methods in solving practical tasks are potential method, Floyd-Worshell method, Dikster method, Bellman- Ford method, Levit method etc.

For all these methods, it is necessary to present transport network in diagrams.

Calculation of communication.

The next stage is to determine the pedestrian movement volume on the elements of road networks. Mobility plan is used for quantitative movement evaluation in network. Its elements are the movement volumes between each pair of nominal areas. Gravity model is the widespread model between others. On the base of gravity model is an assumption that the volume of transport flow from the departure area to arrival area are proportional to the volume of all flows, and function that depends on the transport distance between these areas. Transport distance shows the level of area proximity considering the speed and accommodation of movement, which is given by transport network. The determination method of this value may be different in various versions of the model.

The most widespread and traditional gravity model is based on hypothesis [11, 12]:

$$b_{ij} = k \cdot HO_i^{\alpha} \cdot HP_j^{\beta} \cdot f(l_{ij}), \quad (4)$$

where b_{ij} – potential connections between areas i and j;

k - scale coefficient;

HO_i^{α} - passenger departure volume from area i during calculation period;

HP_j^{β} - passenger arrival volume in area j during calculation period;

$f(l_{ij})$ - gravity function, that shows the distance or time expenditure during the transportation from area i to area j;

α, β - empirical coefficients.

Correlations (4) should be made together with limitations (5) and (6). It provides the balance of mobility plan:

$$\sum_{j}^{n} b_{ij} = HO_i, \quad (5)$$

$$\sum_{i}^{n} b_{ij} = HP_j, \quad (6)$$

where n – quantity of transport area.

In this modelling method, it is necessary to give special consideration to formalization of gravity function [11, 12].

Classical gravity function is defined between the communication size and the distance between areas that usually are expressed in time communication:

$$f(l_{ij}) = \frac{a}{t_{ij}^{k}}, \quad (7)$$

where t_{ij} - communication time between nodes i and j, hour.;

a, k - empirical coefficients that are determined by means of model calibrating with the help of natural researches.

Calculation of foot flows distribution in the network.

The foot flow distribution in network are defined after the mobility plan receiving.

There are several methods of communication determination in network arcs [13, 14, 15, 18].

The easiest one is the method of the shortest distance. According to this method, the communication between each node of pairs "lay over" on the short distance road that connects these nodes. To determine the shortest distance we can use various criteria such as minimum communication time, minimum distance, minimum costs etc. The algorithm of method is to determine the shortest distance mobility with certain criterion. Then, to distribute the communication in network arcs to the shortest calculated routes roads according to nodes.

Experimental research of foot flows parameters.

The aim of experimental regularities researches of foot traffic parameters changes is in the developing of mathematical model that could give a possibility to define the mail transportation parameters. These regularities are necessary to create the communication distribution model in network.

First, we need to determine the generation and absorbing volume of foot flows in the attraction points - places of appearing and absorbing foot communications such as residence buildings, municipal transport stops, parking, organizations and institutions, cultural and social service objects etc.

Next stage of experimental researches is to define the foot flow parameters (intensity, speed, density) on the main communicational routes.

Validity check of foot flow distribution model in the network.

After distribution model development of foot flow in the network, it is necessary to define relative error of model in each arc with next formula:

$$\delta_{Ni} = \frac{\left|N_{\phi i} - N_{pi}\right|}{N_{\phi i}}, \quad (8)$$

where $N_{\phi i}$ – actual intensity value of foot flow on arc *i*, people./hour.

N_{pi} - calculated intensity value of foot flow on arc *i*, people./hour.

The average approximation error of model defines with next formula:

$$A = \frac{1}{n}\sum_{i=1}^{n}\frac{\left|N_{\phi i} - N_{pi}\right|}{N_{\phi i}} \cdot 100\%, \quad (9)$$

where A - average approximation error of model

$N_{\phi i}$ – actual intensity value of foot flow on arc *i*, people./hour.

N_{pi} - calculated intensity value of foot flow on arc *i*, people./hour.

If the average approximation error of model is not over than 10% we can say that the accuracy of developing model is quite enough.

3. Research and Data Analysis

As a part of this work, the main foot flow researches are directed to define the regularities of their formation and absorbing. Four housing complexes in Saltivka building estate (in Kharkov) were chosen as the subjects of researches (figure 3).

Figure 3. Scheme of research district.

This district was bounded by the Blyuhera st, Gvardeytsev Shironintsev st, Akademika Pavlova st, Uborevicha st, Barabashova st.

They are arterial streets of municipal and regional meaning where lay the routes of municipal passenger transport. There are also 2 metro stations «Studencheskaya» «Heroiv Pratsi». The housing development situates in the foot availability range of municipal transport stops.

Within the area of research were defined 304 foot attraction objects, where 159 of them are residential houses, 22 - educational institutions, 31 - retail objects for food and non-food goods with area 30 m^2, 16 objects for car keeping with the capacity of 3200 - car places; 650 foot network nodes and 1286 arcs. Also, here we can add the presence of several High Educational Institutions such as: National Pharmaceutical University, Kharkiv National Teacher's University named by G. S. Skovoroda. Mainly here takes place foot transportation from «Studencheskaya» metro station. Here is suburban bus station near «Heroiv Pratsi» metro station.

Analyzing the residential houses we defined that 9-storey, 12-storey and 16-storey buildings dominate here. For research were chosen two 12-storey buildings with 4 entrances in each. They are on the distance 600 m and 1000 m from "Studencheskaya" metro station. During the researches, we recorded the quantity in people, who enter and go out to building during 5 minutes intervals. All researches took place at workdays at morning hours.

Figure 4, 5 shows the results of buildings researches, that are at the distance 600 m and 1000 m from «Studencheskaya» metro station.

Natural research analyses showed that the building which is closer to metro station has more significant peak hour period compared with further one [19]. Its peak period starts earlier and it is more in tact (Figure 4, 5).

We defined mobility plan with the help of dependency (4) and (7) on the base of time data by generation and absorbing objects volume of foot attraction, actual communications and foot flow intensity on main arcs that were determined by natural method.

Received mobility plan and the shortest distance mobility are as a ground for definition the foot flow in the road network. Average approximation error (9) is not over that 10%

The quality of foot movement is defined by virtue Level of service. (LOS) [16].

According to [16] is possible to define Level of service (LOS) at network particular area.

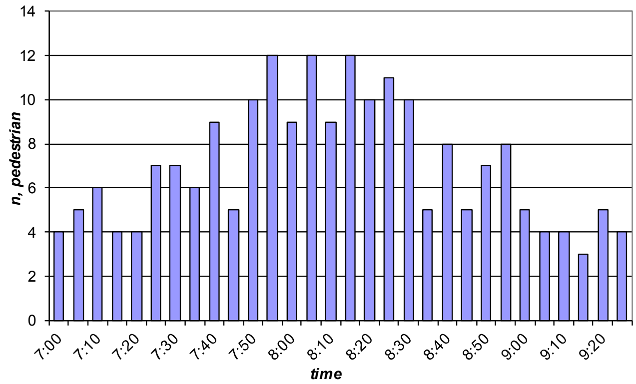

Figure 4. Building on the distance of 600 m from «Studencheskaya» metro station.

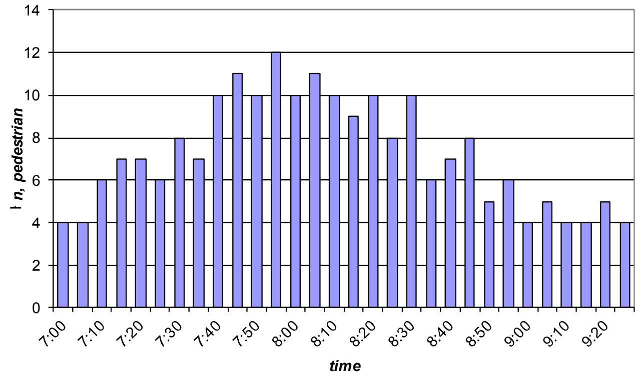

Figure 5. Building on the distance of 1000 m from «Studencheskaya» metro station.

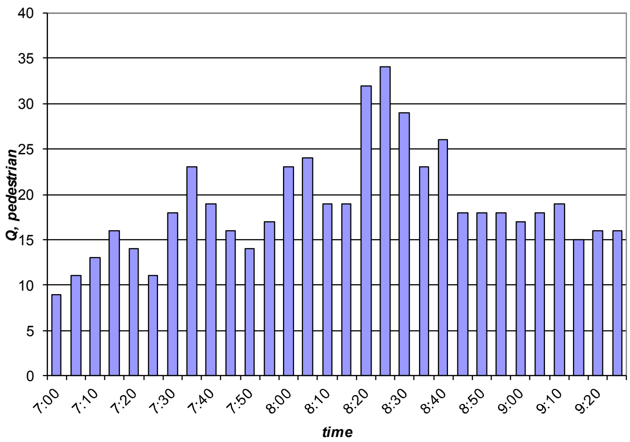

Figure 6. Foot flow on the network arc coming to «Studencheskaya» metro station.

As we see from the natural researches (Figure 4-6), the foot flows are irregular during one hour. Calculated hour meanings of foot flow at network don't give us the objective estimation of service levels during one hour. That's why it was suggested to provide the foot flow modeling which different intervals (equal ΔT). We uses next method [11, 17]:

1. Enter time of foot flow from the departure point i to

arrival point j define with dependence:

$$T_{Bij} = T_{Hj} - t_{nij} - T_{Pij}, \quad (10)$$

where T_{Hj} - departure time in point j;

t_{nij} - movement period of time from point i to point j;

T_{Pij} - the period of reserving time by pedestrians $T_{Pij} = f(t_{nij})$.

2. Ending time of foot flow movement from point i to point j is:

$$T_{3ij} = T_{\text{поточ}} - T_{Bij} - T_{Pij}, \quad (11)$$

where $T_{\text{поточ}}$ - absolute N present time

3. Start time of foot flow movement from point i to point j is:

$$T_{\text{поч}\,ij} = T_{\text{поточ}} - T_{Bij}. \quad (12)$$

4. Location point of foot flow beginning B will belong to transport node L_1 section $L_2 - L_1$ of network road if:

$$\begin{cases} T_{\text{поч}\,ij} > t_{ni,L_2} \\ T_{\text{поч}\,ij} \le t_{ni,L_1} \end{cases}, \quad (13)$$

where t_{ni,L_1} - communication time from departure point i to node L_1;

t_{ni,L_2} - communication time from departure point i to node L_2.

5. Location point of foot flow finishing A will place in node L_2 section $L_2 - L_1$ network road if:

$$\begin{cases} T_{O\,ij} > t_{ni,L_2} \\ T_{O\,ij} \le t_{ni,L_1} \end{cases}. \quad (14)$$

If $T_{Bij} > T_{\text{поточ}}$ -it means that pedestrians didn't go out from point i to point j at the recent time.

If $T_{Oij} < T_{\text{поточ}}$ - all pedestrians have already arrived from point i to point j.

Taking into account given methods it is possible to receive the foot flow characteristics at less time intervals. Figure 7 shows the foot flow model data at network section.

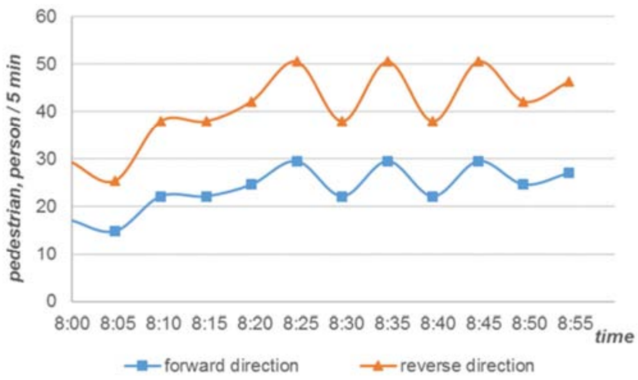

Figure 7. Foot flow model at network arc coming to "Studencheskaya" metro station.

According to [16] during one hour the average square accounts for one pedestrian is 2,58 m^2/h and corresponds to LOS C. Service level will be on the section between from LOS C to LOS E (Table 2) if we analyze 5 min. time intervals.

Table 2. The service level (LOS) during 1 hour.

time	8:00	8:05	8:10	8:15	8:20	8:25	8:30	8:35	8:40	8:45	8:50	8:55
space м^2/p	2,47	2,14	1,99	2,07	1,36	1,70	1,71	2,14	1,99	1,57	1,79	1,89
LOS	C	D	D	D	E	D	D	D	D	D	D	D

4. Conclusions

To calculate and forecast network functional parameters it is appropriate to use modeling of foot flow transportation. Mobility plan is the base for calculation of main foot flow characteristics at network road. Gravity model is widespread method for determination of mobility plan.

Natural research analysis showed that foot flow characteristics change during one hour. The biggest changes happen at the period of peak hour. This is due to that hour pedestrian movement consist of working movement.

To analyze conditions and estimation of quality transportation we use time characteristics of foot flow. However, it is better to divide one hour into short time intervals. It gives the possibility to estimate the quality of pedestrian service more accurate. Used method of parameter determination of foot flow at network road allowed to define that as the whole the service level somewhere is on decentish level but there are some time intervals, where we can see insufficient service level.

The results of given research can be used by specialists both in project activities and in estimation of pedestrian quality service in existing building.

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