Models of Pedestrian Flows for the Concept of Sustainable Development of Moscow Area

Irina Nikishina¹, Tatiana Karyagina², Pavel Mironov³ and Vladimir Churin⁴

¹Moscow Polytechnic University, 38 Bolshaya Semyonovskaya str., Moscow, 107023 Russia
²Russian State Social University, Bld. 1, 4 Wilhelm Peak str., Moscow, 129226 Russia
³Moscow Aviation Institute, 4 Volokolamskoye shosse, Moscow 125993 Russia
⁴Financial University under the Government of the Russian Federation, 49 Leningradsky Prospekt, Moscow, 125993 Russia

Abstract. The article defines the problem of environmental condition of a road segment and the reasons for such condition. Key factors have been defined having a negative effect on the environment. One of the factors is organization of pedestrian traffic in the transport system of the Koptevo district in the Northern Administrative District of Moscow. The research target boundaries have been defined, which are limited by Mikhalkovskaya Street and adjacent area. The research target has been structurally analyzed to identify all key objects and their characteristics affecting the pedestrian flows. Graphical and parametric models of the research target have been developed, which are a basis for modeling scenarios of changes in various characteristics of a real object. Such changes are necessary to develop the concept of sustainable development of the area.

1 Introduction

In the conditions of rapid technological growth, the concept of sustainable development becomes globally relevant [1]. This development is based on preserving the quality of the environment. This requires a balance approach to economic growth and implementation of innovations. Sustainability must be based on the unity of economic, social and environmental goals. In this case, the attention of companies and business communities will be attracted to address the existing issues [2].

The development of residential areas entails modernization and formation of infrastructure facilities, changes in directions and density of transport and pedestrian flows, formation of new attraction centers, etc. Researchers note that the existing transport system and infrastructure do not cope with the increased traffic and passenger flows [3, 4]. First of all, this is related with the existing historically compact urban planning.

* Corresponding author: ira-nik@mail.ru
As traffic increases, cities do not transform their transport networks. Therefore, pedestrians have to cover long distances to a nearest public transport stop, walk in a dense pedestrian flow due to no convenient connection hubs, no smart traffic lights based on the density of pedestrian and traffic flows, increased downtime, no convenient public transport, etc. [1, 5, 6]. This can literally paralyze the transport network of a whole city. The major negative consequence of this will be a significant environmental pollution.

In this manner, the goal of the research is synchronization of transport flows with the transport system of the district ensuring reduced waiting times.

The objectives pursued during the research include: formation of a list of objects in the subject domain involved in pedestrian flow formation; setting out the rules for interaction of the existing objects with the external factors and between each other; formalization of the identified rules in the form of graphical models; creating parametric models that help modeling pedestrian flows in the subject domain.

The theoretical significance of the research is setting out the parameters and their qualitative and quantitative characteristics defining traffic flows in the subject domain. The research findings can be used to create various models to model scenarios of changes in subject domain components in order to develop an adequate mechanism and instructions for prompt response.

The practical significance is an ability to use the findings to implement the urban planning strategy in residential areas to ensure environmental welfare.

2 Objects and Methods

The target of the research is pedestrian flows formed along Mikhalkovskaya Street (500 m) in the Koptevo District of the Northern Administrative District of Moscow. The area under study is limited by Matros Zheleznyak Boulevard on one end and Pryanishnikova Street of the other end.

Creating real-world models is a complex process requiring an integrated use of methods.

The first stage of the research required description of the subject domain including the list of all objects and links between them. To address this issue, the structuring method was used [7]. The need to obtain such objects is based on forming input parameters for models, including imitation models [1, 8, 9]. Each object has qualitative and quantitative characteristics that may depend on each other or some other factors. Such characteristics
and their dependencies were set using the *analysis and synthesis methods* [5, 9, 10]. Those characteristics from the ones obtained were removed, which are insignificant or irrelevant to address the issue of sustainability. The convergence method was used for such exclusion.

The objects, their characteristics and links were formalized at the **second stage of the research**. Using the *graph theory method* allowed for representing the movements of pedestrian flows as a network. This form of representation is illustrative and suitable for making parametric equations necessary to develop a parametric model [4, 6, 11]. Moreover, the graph makes it possible to evaluate the efficiency of routes in the area in terms of required time. To specify individual characteristics of the graph, diagrams were created using the graph method. This helped find the link between the formalized objects and the real object of the street road network. The resulting diagrams supplemented and clarified the graph.

Equations describing pedestrian flows depending on certain situations were obtained **at the third stage** using the *parametric modeling* method.

### 3 Results

To create a graph model reflecting pedestrian flows, key objects must be identified. Pedestrian flows are formed in the area under study upon the following rules:

**Rule 1.** Local citizens go to their places of residence from public transport stops, social areas (shops, parks, etc.) or other blocks. To determine nodes associated to zoning of residential facilities, respective areas were distinguished (Fig. 2).

**Rule 2.** Pedestrian flows move towards Pryanishnikov Street or Sobolevsky Proyezd. The reverse is also true: the flow going from Sobolevsky Proyezd comes to Mikhalkovskaya Street (similar to the pedestrian flow from Pryanishnikov Street). Fig. 3 shows main directions of entrance and exit from the area under study.

![Fig. 2. Zoning of the research target by principle of residential and public facilities](image-url)

It should be noted that this does not take into account passages within closed grounds near buildings since they have almost no effect on primary pedestrian flows along the area under study.

**Rule 2.** Pedestrian flows move towards Pryanishnikov Street or Sobolevsky Proyezd. The reverse is also true: the flow going from Sobolevsky Proyezd comes to Mikhalkovskaya Street (similar to the pedestrian flow from Pryanishnikov Street). Fig. 3 shows main directions of entrance and exit from the area under study.
Fig. 3. Directions of pedestrian flows entering or exiting the research target

Rule 3. When moving along the area under study, flows can be retarded for a short time. This is caused by signal-controlled and zebra pedestrian crossings. Arrows in Fig. 4 show places where pedestrian have to stop due to crossings.

Fig. 4. Locations of pedestrian stops in the area under study

Rule 4. Pedestrian may stop at a public transport stop waiting for a tram or a bus. Moreover, new pedestrians in the area under study may get off the public transport. Fig. 5 shows public transport stops.

Fig. 5. Public transport stops at Mikhalkovskaya Street

These rules were used to develop a non-oriented graph suggesting traffic between nodes in two directions (Fig. 6).
Fig. 6. Graph modeling pedestrian flows in the area under study

The graph represented in Fig. 6 can be transformed: the weights of each rib are set depending on characteristics that can be investigated. Such characteristics include: time required to walk from one node to another, distance between nodes, density of pedestrian flows at certain time, etc.

The analysis helped the authors to develop a parametric model describing characteristics of pedestrian flows. Let us present one of them.

Pedestrian traffic model in case of biphase traffic light. Duration of intermediate cycle when pedestrian traffic is organized in two directions:

$$t_{nn_i} = t_{1i} + L_{nn_i} \left( \frac{V_{np}}{q'_i + q''_i} + \frac{1}{V_{np} + V_{np}'} \right) + 2 \frac{l_{ni}}{(V_{np})_{min}}, \quad (1)$$

where $t_{1i}$ is the average response time of a pedestrian to signal changing from green to red; $L_{nn_i}$ is the pedestrian crossing length;

$q'_i$ is the density of pedestrian traffic per long meter of crossing length on its right side relative to drivers;

$q''_i$ is the density of pedestrian traffic per long meter of crossing length on its left side relative to drivers;

$(V_{np})_{max}$ is the maximum rated speed of counter-flows of pedestrians;

$q''_i + q''_i$ is the reverse value of speeds of mixed pedestrian flow in counter directions.

Let us describe each element in Table 1.

**Table 1. Description of cycle duration model elements in pedestrian crosswalk organization**

<table>
<thead>
<tr>
<th>No.</th>
<th>Parametric description</th>
<th>Characteristic</th>
</tr>
</thead>
<tbody>
<tr>
<td>5</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Reverse value of speeds of mixed pedestrian flow in counter directions

Movement duration of mixed pedestrian flow along pedestrian crossing length

Movement duration of mixed pedestrian flow when moving to a distance equal to the portion of the crossing by the time when the flow is divided into individual pedestrian groups in the end of crossing

Movement time of individual pedestrian groups after the mixed flow is divided near the crossing boundaries

Movement time of the last pedestrian from the waiting location to the exit from the driveway

In this manner, the pedestrian traffic intensity can be predicted on signal-controlled pedestrian crossings [11].

4 Discussion

Intensity growth of transport and pedestrian flows is a factor necessitating the scientific approach to evaluating conflict points. Such points are formed at the crossing of traffic arteries, in locations of signal-controlled and zebra pedestrian crossings, at public transport stops, etc. The researchers note that this creates potential accidents and has a negative effect on the environment [5, 10, 12]. A solution for these problems in researches is creating methods and models that calculate prediction estimates of hazard and traffic delays in road segments [9, 11, 13].

The research results in similar papers are aligned with what is found by the authors hereof. When addressing the claimed problems, Russian and foreign researchers identify all sources affecting the transport system [9, 10]; systematize the subject domain and define dependencies characterizing each respective object [1, 3, 6]; create models demonstrating a potential response of the transport system to scenarios of varying input parameters [11, 12, 13].

5 Conclusion

Identifying the influence patterns of transport and pedestrian flow density and intensity, waiting times in areas of pedestrian crossings and delays in public transport traffic affect the throughput capacity of the street road network. This results in an increased environmental pollution, which makes it uncomfortable and sometimes even dangerous to stay or dwell in respective areas.

Organization of pedestrian traffic affects the location of public transport stops, location of pedestrian crossings, configuration of traffic lights on signal-controlled crossings. Implementing each of the above processes is a complicated task requiring time and resources that help predicting the changes in the scope and nature of such flows.

The created models resolve the problem of long-term area planning and prompt management of flows in the smart city system in real time. The findings of this research comply with all requirements of the subject domain and reflect all its qualitative and quantitative characteristics. This is confirmed by using common scientific methods,
adequacy and validity of the findings and their compliance with the Russian and foreign researches in this area.

References

1. N.A. Naumova, Determining the Parameters of Dense Pedestrian Flow During Stready-State Movement in Certain Direction, Modern high technologies, 10, 62–67 (2020)


