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safety; simulation modeling; push-button traffic lights; road accidents

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SIMULATION MODELING IN IMPROVING PEDESTRIANS' SAFETY AT NON-SIGNALIZED CROSSWALKS

Summary. The paper presents an analysis of road traffic accidents at non-signalized pedestrian crosswalks. A field study was conducted to determine the parameters for traffic and pedestrian flow, and construct the simulation models enabling experimentation at different loadings on the street and road network. Variants for improving the pedestrian safety at non-signalized crosswalks have been proposed. Simulation modeling of the proposed managerial decisions is expected to diminish the likelihood of road accidents. The efficiency of proposed decisions has been estimated.

ОЦЕНКА ВОЗМОЖНОСТЕЙ ПОВЫШЕНИЯ БЕЗОПАСНОСТИ ПЕШЕХОДОВ НА НЕРЕГУЛИРУЕМЫХ ПЕРЕХОДАХ С ПОМОЩЬЮ ИМИТАЦИОННЫХ МОДЕЛЕЙ

Аннотация. В статье проанализированы варианты возможных ситуаций возникновения ДТП на нерегулируемых пешеходных переходах. Проведены натурные исследования параметров движения транспорта и пешеходов на таких участках улично-дорожной сети. Определены параметры транспортных и пешеходных потоков, построены имитационные модели и проведены эксперименты на них при разных нагрузках на улично-дорожную сеть. Предложены варианты улучшения ситуации на нерегулируемых пешеходных переходах. Выполнена проверка на моделях предложенных управленческих решений, которые позволят снизить вероятность дорожно-транспортных происшествий. Выполнена оценка эффективности предложенных решений.

1. INTRODUCTION

In 2015, the UN General Assembly extended the list of Sustainable Development Goals (SDGs) by including a new target of halving the global number of deaths and injuries from road traffic crashes by 2020. As indicated by the WHO Global Status Report on Road Safety 2015, plateauing of road traffic deaths despite 4% increase in global population and 16% motorization in the past few years, show that implementation of road safety measures has led to saving lives.

It was stated that almost half of all deaths on the world's roads are from the least protected – motorcyclists (23%), pedestrians (22%), and cyclists (4%). The death toll varies by region, being highest in Africa for pedestrians and cyclists - 43%, and relatively low in South-East Asia (Fig. 1).

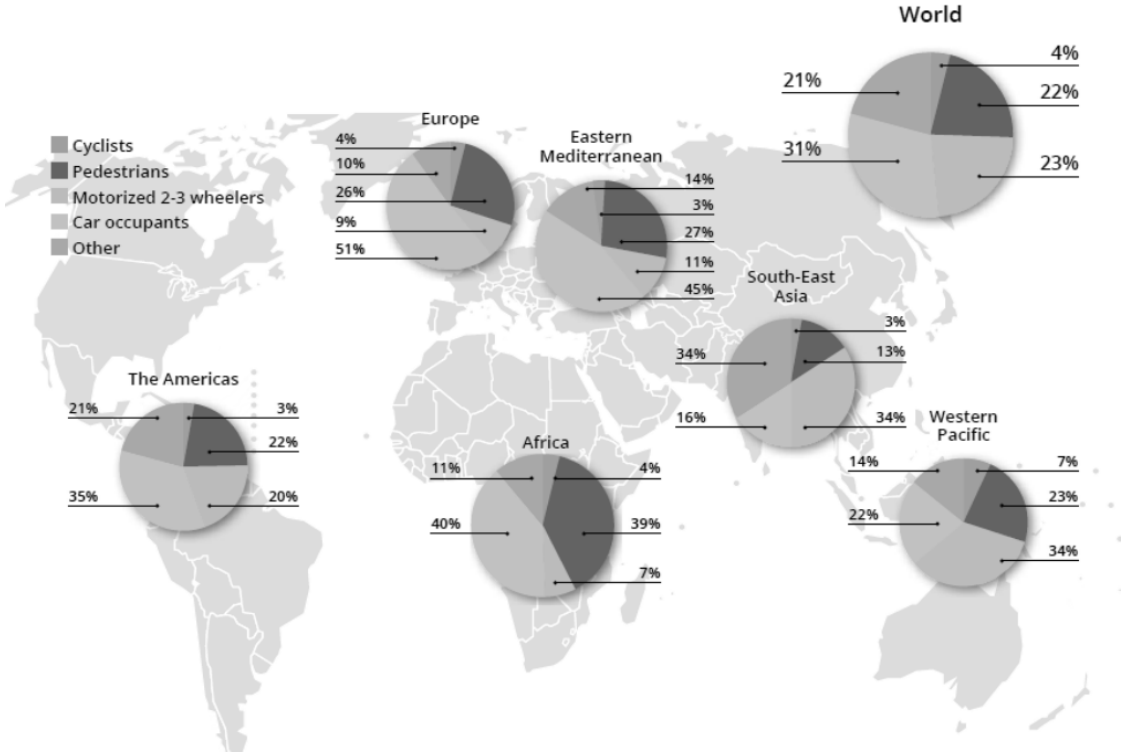


Fig. 1. Road traffic deaths by type of road users [1]
Рис. 1. Смертность в дорожно-транспортных-происшествиях по типам участников ДТП

As pointed out in the WHO report, not enough attention is paid to the needs of pedestrians, cyclists and motorcyclists, although the number of road traffic deaths account for 49% worldwide [1].

In Russia, the concept of transport development emphasizes the priority of public transport is providing safety for pedestrians and cyclists, and differentiating transport flows. Implementation of the transport concept essentially relies on improved traffic signalization.

Urban traffic control schemes often have to be alternated, in response to the following factors: an emergence of new attraction centers and building estates, rearranging road-street networks and route networks and increasing motorization. In these cases, informed managerial decisions are made using simulation modeling [2].

2. STATE OF THE PEDESTRIAN SAFETY ISSUE

2.1. Peculiarities of traffic signalization

To ensure the safety of road users, the traffic lights are usually installed at areas of anticipated, or actually occurring accidents, which can be avoided using signalization, or when other measures (such as speed restriction, overtaking prohibition or zebra crosswalks) have proved ineffective. Traffic signalization is helpful in the following situations:

- High concentration of road accidents caused by violation of the crossing priority rule:
  - Intensive vehicular traffic, or too high permissible speed, along the main road.
  - Restricted view or impossibility for the motorist to make a decision about the priority rule at crosswalks.
  - Insufficient intersection capacity at the crosswalk.
- High accident rate at areas with vehicles turning left and opposing traffic.
- High accident rate between vehicles and cyclists or pedestrians crossing the road.

The introduction of push-button signalization can essentially improve the quality of traffic along the entire road-street network and at mid-point crossings and intersections. In particular properly adjusted sets of traffic lights at intersections assist both the public transport and non-motorized traffic participants (cyclists and pedestrians). Many countries apply signalized pedestrian crossings, granting pedestrians minimal waiting time and allowing vehicles to continue uninterruptedly if there are no pedestrians in view.

The main advantage of signalized pedestrian crossings consists in providing both motorists and pedestrians a clear perception of the situation at intersections. Instead of solving a complex, logical-physical task, they are offered to react primitively to a light signal, with a conditioned reflex. A flashing red signal can be seen from afar, and it is located along the motorists' glance trajectory, allowing them to concentrate on the road, and time to decelerate. Signalized pedestrian crossings do not increase the risk of an accident because pedestrians cross the road only when the light is green.

Therefore, signalized crosswalks at busy road intersections, accommodating a few pedestrians in a unit of time but still convenient for many as part of a substantiated route (crossing towards a public transport stop, school, shop, etc.), are a means of guaranteeing safety for pedestrians, without unreasonable traffic delays. In Europe, where priority is given to pedestrians, there are numerous signalized crosswalks and practically no non-signalized ones across busy four-, and more, lane roads [3].

2.2. Pedestrian safety research

Transport safety issues are topical in many countries, especially in the transport systems of major cities. Urban sustainability is affected by different factors some of which are difficult to formalize or control. One of the problems is managing interactions between the pedestrian and transport flows.

Statistics show that the number of pedestrians dying each year in road crashes includes 186 300 children [4]. The problems of road safety and elimination of dangerous road situations have been studied extensively, focusing on the vehicular - pedestrian interaction.

The causes of noncompliance with crossing rules were identified from field study observations of pedestrian behavior, and distributing questionnaires to the same participants to acquire demographic and socioeconomic characteristics [5]. It is expected that this analysis will increase the awareness of traffic engineers, city builders and politicians, and lead to more efficient traffic control at intersections. Pedestrian behavior was surveyed at two signalized intersections in Doboj, Serbia [6], and included analyses of video observations of the crossing behavior and factors influencing it.

It is reported [7] that the major reasons for pedestrian noncompliance with traffic signals are low quality traffic management, traffic volume and long waiting time. In work [8], it is shown that designing a signal should take into account the use of adjoining land, and the results of traffic surveys. Another risk factor is the conflict between vehicular and pedestrian flows at left-hand corners [9, 10]. As revealed in studies [3], almost 30% of pedestrian injuries occur at non-signalized crosswalks. Factors of fatality risks were used to model a binary logistic regression, which treated the statistical information provided by the police.

Different risk assessment models have been proposed as well as measures to improve pedestrian safety. Thus, the model proposed in the work [11] allows measuring the impact of potential risk factors on pedestrians' intended waiting times during the red-man phase of the traffic lights. In a later work, the author proposes a multivariate method of risk analysis consisting of two hierarchically generalized linear models. They characterize two different facets of risky crossing behavior, using a Bayesian approach with the data augmentation method to draw statistical inference for the parameters associated with risk exposure.

Relation between vehicle travel speed and pedestrian injury risk is explored in the research [12]. The authors took into account age group of pedestrians and vehicle type (sedans and light passenger cars). The authors determined that elderly age group (60 years old and over) faces higher risks of serious injury and fatality than both the child age group (12 years old and under) and the mid-age group (13–59 years old). The authors suppose that the findings should be included in designing specifications for pedestrian detection system soon.

Simulation is successfully applied in assessing the variants of improving pedestrian safety. In work [13] the authors propose a method for estimating the needed crosswalk widths, taking into account different combinations of pedestrian demands and a predetermined level of service. The method involves theoretical simulation of the total crossover time at signalized intersections. Traffic lights phase optimization, using simulation models, allows finding a balance between mobility, safety, and environment [14]. Authors of the research [15] to simulate pedestrian and vehicle crossing behaviors at signalized intersections created cellular automata-based model. The optimal signal timing was determined using the bidirectional pedestrian flow model [16].

The impact of traffic light control parameters on the frequency of accidents and the severity of its consequences is explored in work [17]. The authors conclude that intersections with concurrent phasing have fewer total pedestrian crashes than those with exclusive phasing, but more crashes at higher severity levels. It is recommended that exclusive pedestrian phasing only is used at locations where pedestrians are more likely to comply.

The task of synchronization of traffic lights and selection of the optimum value of the phase time can be successfully solved by simulation. The authors [18] determined that all discrete cycles, with their extended phases and corresponding crosswalks, can be stored in a file and retrieved whenever the data of the movements are updated so as to adjust the green time accordingly to every phase, and finally choose the cycle that corresponds to a predetermined optimality criterion.

3. RESULTS AND DISCUSSION

As can be seen from the above review, pedestrians are the least protected road users and pedestrian safety topic is relevant worldwide. Scientists use different methods to study ways of solving a problem. Various methods are used for such purposes, such as identification of the causes of road traffic offenses and modeling of the transport system. The experience of similar studies shows that simulation modeling is the preferred method. This is due to several reasons: availability of instrumentation for the construction of micro models, the ability to make computer simulation on the model for different values of the parameters of motion, lower cost compared to other methods and the ability to quickly get the result, if necessary, adjust models. Furthermore, since the result of field surveys is the original data, the appropriate verification, validation and calibration of the model can predict the behavior of the real system, in case the situation changes. Also, the visibility of such models is important because of the visualization tools available in most simulation software.

3.1. The purpose and methodology of the study

Pedestrian safety problem in Russia is quite acute, especially in old cities and metropolitan areas, where the infrastructure and road network cannot cope with the increased level of motorization. According to statistics, accidents involving pedestrians are caused by violation of traffic regulations by drivers or pedestrians. If we analyze the reasons, the greater impact on the number of accidents has traffic density. Thus, the authors [19] come to the sad conclusion that the pedestrian crossings (even signalized pedestrian crossings) are unsafe. The authors analyzed the signalized and nonsignalized pedestrian crossings. At similar values of a total number of accidents, the total number of victims is much higher at the unsignalized pedestrian crossings. In Chita (Siberian Federal District, Russia), road accidents caused by drivers constitute 95.2%, and every third accident with pedestrians happens at a pedestrian crossing [20]. Research conducted in Saratov found that children are the least protected pedestrians [21].

Since projects for the reconstruction of the road network are costly, it is desirable to perform an earlier comparison of several options and choose the most effective.

The aim of the study was to select the best options to improve safety at pedestrian crossings at areas with high level of accidents.

To test rationality of the proposed solutions, the following tasks have been allocated:

- studying accident statistics, identifying problem areas with high concentrations of accidents involving pedestrians, including children;
- conducting field surveys of traffic and pedestrian flows, the intensity of traffic and pedestrian flows;
- conducting field surveys of the distribution of air pollution level of Naberezhnye Chelny city;
- developing software modules for input, storage, and analysis of statistical data obtained during the study;
- developing simulation models of problem intersections;
- verifying, validating and calibrating of the model according to data from the research of the real system;
- conducting an experiment on the model and drawing up results.

3.2. Research of parameters of traffic flow

Optimizing urban transport system management starts with an analysis of road situations which is most effective if based on fieldwork, consisting of recording of real conditions and traffic indices of events happening in a specified period. Field work is the only means of obtaining reliable information about the state of the roads and existing vehicle and pedestrian flows. The best-quality information for selecting road sections with highly intensive traffic is obtainable from the State Inspectorate for Traffic Security (SITS) databases.

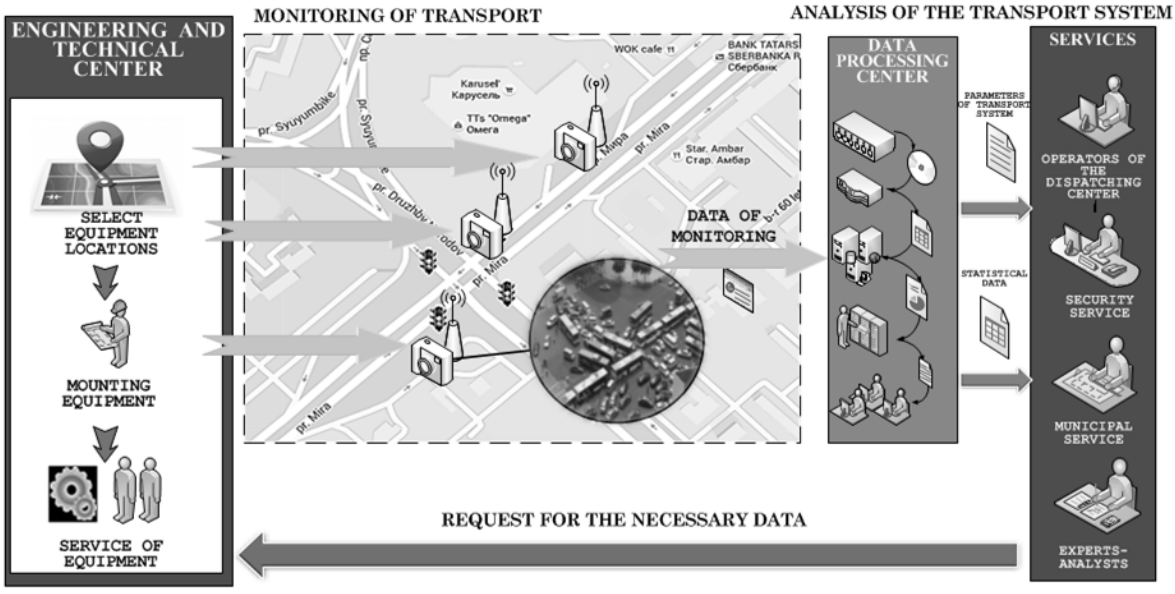


Fig. 2. Conceptual diagram of traffic monitoring
Рис. 2. Концептуальная схема управления движением

Nowadays, Russia is implementing a “Safe City” program aimed at improving the key safety parameters of a modern city by applying video monitoring, access control systems, systems of housing and utilities management and organizational arrangements. The “Transport Safety” section of the program [22] states the following tasks for ensuring road traffic safety:

a) management of public and private transport logistics;
b) organization and management of municipal parking areas;
c) simulation of transport flows proceeding from an analysis of predicted road situations;

d) dynamic prediction of road situations based on real -time data coming from video cameras, traffic sensors and controllers;
e) locating and recording of road events with visualization on the city map.

In compliance with these directions, the city of Naberezhnye Chelny will have 1020 video cameras installed by the end of 2016. This will provide real-time information necessary to make timely managerial decisions as well as to correct the strategy of long-term development of the transport system (Fig. 2).

3.3. Signalized crossing in promoting pedestrian safety

Research for selecting road sections is based on SITS databases. The SITS data were analyzed to reveal the area of most frequent running-down accidents. This turned to be Chulman Avenue, with a rather dense traffic flow and high speed, and absent signalized pedestrian crossings. A long stretch of the Avenue borders the local recreation area, located in a parkland on one of its sides, and schools, kindergartens, and sports and fitness centers, on the other.

As a rule, risky behavior characterizes children and teenagers. The results of surveying Belgian school children's street-crossing behavior [23], conducted with the aid of specially-developed questionnaires, correlate with those obtained in New Zealand, Britain and Spain, which indicate the applicability of this questionnaire to dissimilar countries, cultures, and languages.

For monitoring transport and pedestrian flows, three nonsignalized pedestrian crosswalks (Fig. 3) located in immediate proximity of sports facilities, schools and kindergartens were selected.

Fig. 3. Location of educational institutions near unregulated crosswalks
Рис. 3. Расположение учебных заведений вблизи нерегулируемых пешеходных переходов

Video recordings have displayed that transport at these sections often run at high speed (60 km/h), without prioritizing the pedestrians, which leads to frequent running-down accidents.

Video recording, with subsequent computer image processing, was made on weekdays during the rush hours at 1) 07:00-10:00 am and 2) 17:00-20:00 pm.

The average transport flow speed was found to be 50 km/h-65 km/h; the safe stopping distance, in this case, is 40 meters. This, along with the fact that the separating strip running along the avenue, is planted with trees and shrubs thereby obstructing motorists' vision; and inadequate lighting makes the crosswalks dangerous for pedestrians.

For more detailed analysis, we constructed a simulation model which took into account the section geometry, density, and intensity of the transport and pedestrian flows. The initial data for the model were treated results of video observations. After the model's verification and validation, we performed a validation experiment that afforded to determine the transport and pedestrian flow parameters at regular and peak loadings (Fig. 4).

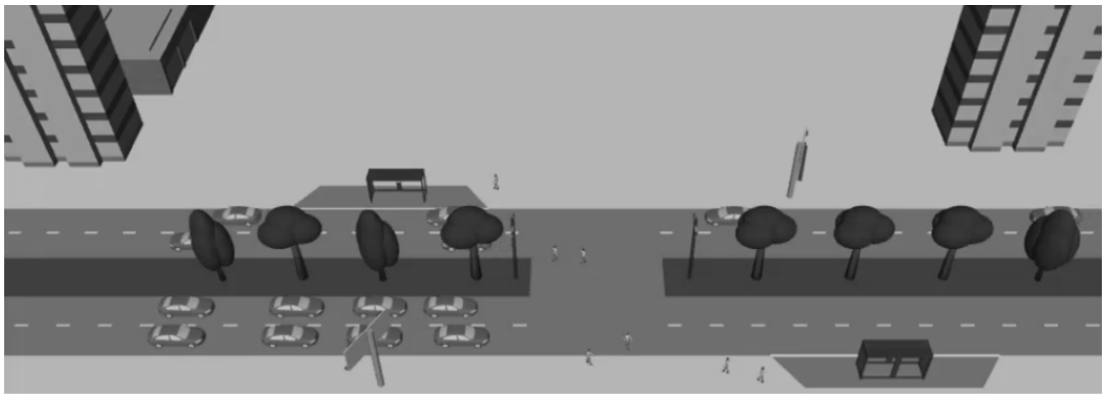


Fig. 4. View the model of considered site (before the modification)
Рис. 4. Модель участка дороги до реконструкции

We hypothesized that installing a set of traffic lights with a push-button green signal would reduce accident risk, without noticeably affecting the speed of transport flow.

In conditions of unstable pedestrian flow comprising many children, this was expected to diminish the influence of behavioral factor on crossover safety. At the same time, signalized regulation would alert motorists, while hardly affecting the average values of transport flow parameters. The hypothesis was tested by modifying the model and including traffic signalization (Fig. 5).

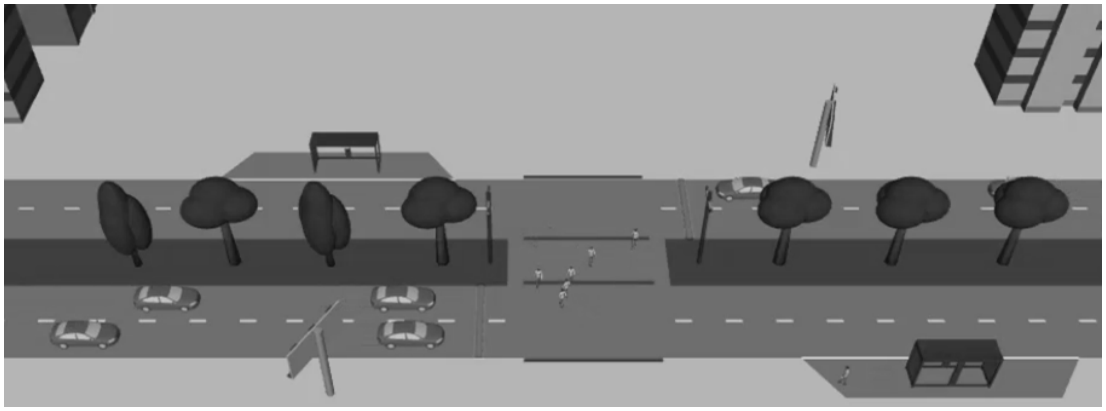


Fig. 5. View the model of considered site (after the modification)
Рис. 5. Модель участка дороги после реконструкции

The results of experiments on the model are shown on Table 1.

By applying the direct search method based on meta-heuristic algorithm, we calculated the most suitable parameters of signalized crossing, providing safety for pedestrians and a free passage for motor vehicles.

Table 1

The results of experiments on the model

Parameters of traffic flow	Without traffic light	With traffic light	
		During typical hours	During rush hours
Average traffic density	121	137	168
Average vehicle speed	71	70	66
Road accidents probability	0.67	0.29	0.24

A feature of the planning decision of Naberezhnye Chelny city is that industrial and residential areas are distinctly separated. Avenues connect enterprises and living areas. Pedestrian flow is generated before and after work shifts on these avenues. Also, density of vehicular traffic increases as well as the risk of road accidents on nonsignalized crosswalks.

We explored one of such nonsignalized crosswalks (Fig. 6). Earlier, several fatal accidents were observed on this crosswalk.

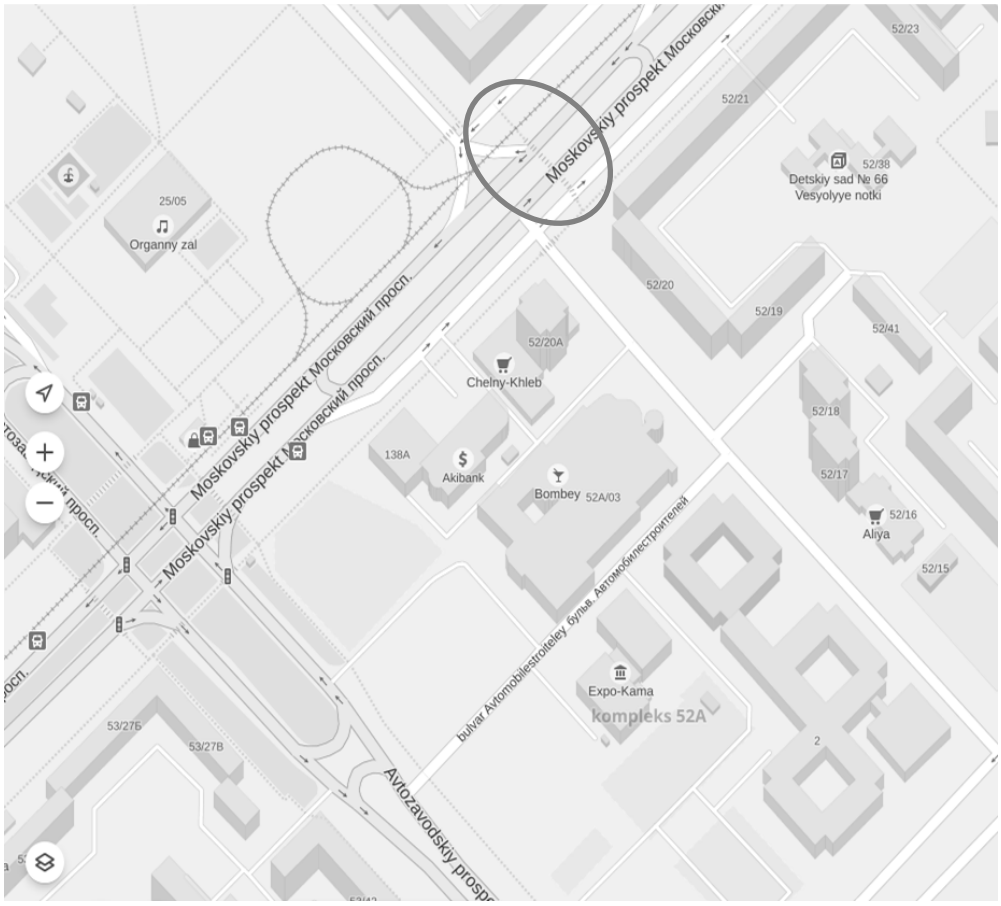


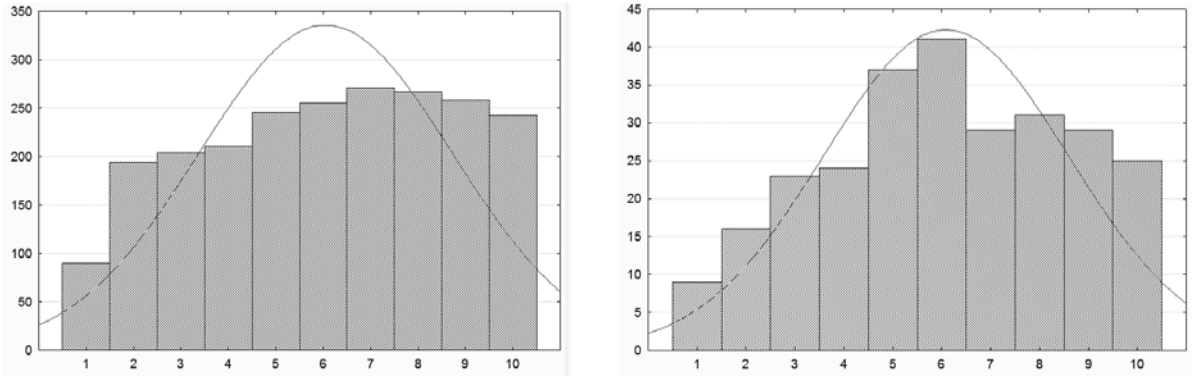
Fig. 6. Analyzed crosswalk
Рис. 6. Исследуемый пешеходный переход

On Moskovskiy prospekt, also, video recording with subsequent computer image processing was made on week days during rush hours at 1) 07:00-10:00 am and 2) 17:00-20:00 pm (Fig. 5). The results of field surveys are shown on the table 2 and charts (figure 7a, b)

Table 2

The results of field surveys

Number of interval	1	2	3	4	5	6	7	8	9	10
Hours	16:00	16:10	16:20	16:30	16:40	16:50	17:00	17:10	17:20	17:30
Vehicles	90	194	204	210	246	251	271	267	258	243
Pedestrians	9	16	23	24	37	41	29	31	29	25



a) density of vehicle traffic flow b) density of pedestrian traffic flow

Fig. 7. Parameters of traffic, based on the results of field surveys
Рис. 7. Параметры движения по результатам натурных наблюдений

It was found that pedestrian flow is high and stable at this time. There were traffic jams before the intersection because vehicles had to give way to continuous pedestrian flow. The experiment on the model showed the installation of a traffic light and its synchronization with nearest traffic lights. The results of experiments on the model are presented in Table 3 and Fig. 7, 8.

The results of experiments on the model are shown in Table 3.

Table 3

The results of experiments on the model

Parameters of traffic flow	**Without traffic light**	**With traffic light**	
		During typical hours	**During rush hours**
Average traffic density	151	145	223
Average vehicle speed	62	70	60
Road accidents probability	0.57	0.27	0.23

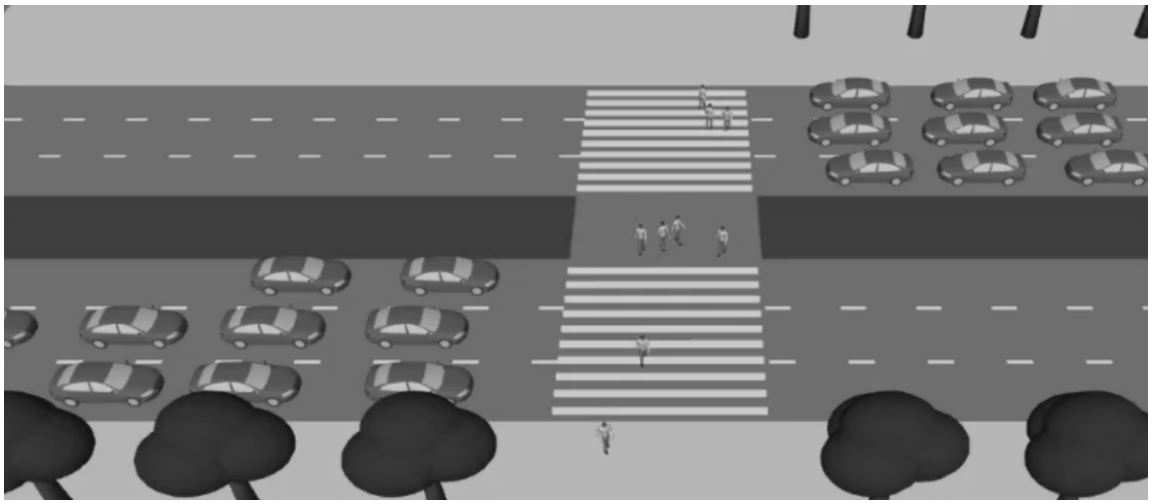


Fig. 8. View of the model showing considered site of Moskovskiy prospekt (before modification)
Рис. 8. Модель участка Московского проспекта до реконструкции

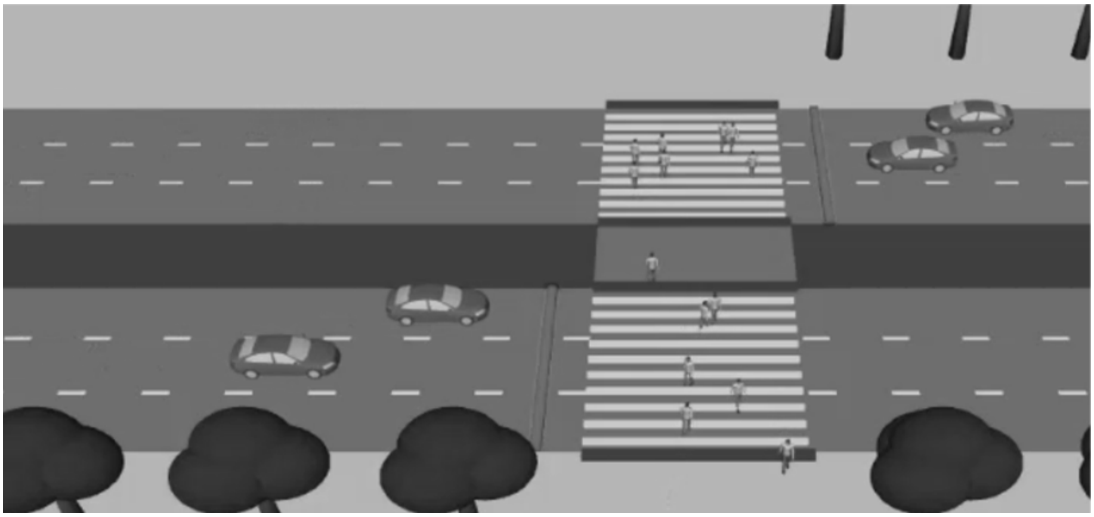


Fig. 9. View of the model showing considered site of Moskovskiy prospekt (after modification)
Рис. 9. Модель участка Московского проспекта после реконструкции

4. CONCLUSION

This study has demonstrated the applicability of simulation modeling in decision-making, aimed at ensuring pedestrian safety at intersections. Selecting an optimal waiting time interval will diminish the likelihood of accidents with pedestrians, without much detriment to transport flow parameters. The quality of decisions will depend on the quality of initial information, which is expected to improve upon implementation of the “Safe City” program. As a result, experiments on the model established that the best solution is the use of a traffic light with button, phase-locked with previous intersection traffic light. Because pedestrian flow is unsteady and, the flow density is increased in morning and evening hours, which coincides with increased traffic intensity. The standby phase control can be applied with fuzzy logic. This application will be in the next studies.

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