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CONTRIBUTION TO SIDEWALK PEDESTRIAN LEVEL OF SERVICE ANALYSIS

Summary. Our main aim with this paper is to contribute towards the methodologies on the level of service which the pedestrians as vulnerable road users feel walking along the sidewalks, as well as contribution towards the process for modeling and simulation on pedestrian's movement. Namely, microscopic simulation model SFStreetSIModel, version 1.0 has been developed which simulates movement of vehicles and pedestrians on two-lane two-way section on low speed urban street. Beside the remaining outer parameters, SFStreetSIModel, version 1.0 simulates 15 minutes intensity on pedestrians on directions, as a measure on the level of service for pedestrians under influence of side friction caused by static obstacles on the road and the sidewalk: on-street parking and street furniture. Here, the modal which refers on the modeling condition, parameters and attributes, as well as the process elements for determination of the level of service for pedestrians, will be shown.

WKŁAD W ANALIZĘ POZIOMU USŁUGI DLA PIESZYCH NA CHODNIKU

Streszczenie. Głównym celem niniejszej pracy jest przyczynienie się do rozwoju metodologii analiz poziomu usługi, którą odczuwają piesi jako użytkownicy ulicy, poruszając się wzdłuż chodników, jak również wkład w proces modelowania i symulacji ruchu pieszych. Został rozwinięty mikroskopijny model symulujący SFStreetSIModel, wersja 1.0, który symuluje ruch samochodów i pieszych na dwupasmowym i dwukierunkowym odcinku wolnej ulicy miejskiej. Obok pozostałych parametrów wyjściowych, model symuluje też piętnastominutowe natężenie ruchu pieszych jako miarę usługi dla pieszych pod wpływem tarcia statycznego wywoływanego przez statyczne przeszkody na ulicy i chodniku: parkowanie na ulicy i sprzęty miejskie. Zostanie tutaj przedstawiony moduł, który odnosi się do modelowania stanu pieszych w dowolnym momencie czasu (t), ich atrybuty i elementy procesu potwierdzające poziom usługi dla pieszych.

1. INTRODUCTION

The concept for sustainable urban development is of a special interest for analysis in the developing countries, countries with low developed economy, demographic and economic rise and infrastructure with low capacity and design. That is, the resulting problems caused low missed ability on the functional elements on the streets, fall of the quality of the transport system, higher number of incidents and degrading of the environment, which is a result by saturating the streets traffic, polluting the environment, lower safety and comfort while traveling, rise of stress by all the users of the traffic systems but special lowered security for Vulnerable Road Users - VRU, that is pedestrians and cyclist.

The pedestrians and the cyclist are unprotected or vulnerable category in the traffic. In the EU cities the vulnerability is explained by the number of incidents in which pedestrians are involved in 15-30% of the total number of accidents. According to the report “Forgiving Roadsides” of the European Transport Safety Council – ETSC, (2008) is considered that pedestrians will survive an accident with motor vehicle if the speed is up to 30 km/h, which shows that the pedestrians should be separated from the fast traffic. The flexibility of the pedestrians is a privileged to themselves, but at the same time a problem when they are in heterogeneous traffic flow. The pedestrians are insufficiently stable and insufficiently visible in comparison with the vehicles, lack which is increased in night conditions. Finally, the pedestrians have different capabilities: children with insufficient experience, old people, old people with limited opportunities and people with limited mobility.

Among the best known European studies in which the research subject are the vulnerable participants in the traffic are MASTER-Managing Speeds of Traffic on Europeans Roads [10], DUMAS-Developing Urban Management And Safety [4], PROMISING-Promotion of mobility and safety of vulnerable road users [12] and WALCYNG-How to enhance Walking and Cycling instead of shorter car trips and to make these modes safer [18]. The basic safety principles and the measures extracted with the analysis of these studies are presented on Tab. 1.

Table 1

Preview of the elementary safety measures and the principles obtained from the analysis of the most famous study for the vulnerable road user

Study	Safety principles, measures and strategies
MASTER	1. Comfort which means higher quality on the surface for the pedestrians and cyclist; 2. Limited speed from vehicles especially on residential, industrial and historic streets; 3. Coherence, continuity on pedestrians paths.
DUMAS	1. Removing all obstacles which do allow movement or low view on safety 2. Atractive or appropriate labelling, regulating and lightening the pedestrians paths and cyclist lanes.
PROMISING	1. Sufficient level of service for pedestrians; 2. Sufficient level of service for cyclist; 3. Managing with pedestrians and cyclist flow; 4. Adequate view; 5. Planning land use in order to decrease the risk for pedestrians and cyclist; 6. Informing pedestrians and cyclist.
WALCYNG	1. High safety for pedestrians; 2. High safety for cyclist; 3. Managing with pedestrians and cyclist flow; 4. Change of attitudes and the behavior of drivers by informing, training and enforcement of law.

2. CHARACTERISTICS AND PARAMETERS OF PEDESTRIAN FLOWS

The basic characteristics for pedestrians in the traffic flow naturally are similar with the characteristics of the flow of motor vehicles. But, they are specifics, like: possibilities for cutting the flow for pedestrians, movement in opposite direction and maneuvering without conflicts and change of speed.

The characteristics and parameters needed for determining the Level Of Service - LOS for pedestrians on the sidewalks are shown on the following Tab. 2

Table 2

Characteristics and parameters for confirming the pedestrians LOS on the sidewalks

Characteristics	Parameters
Comfort – adequate protection from weather conditions, protective fences	**Speed of pedestrians [m/min]** – average speed of movement
Safety-dangers connected with vehicles, interference and the situation the pavement is in	**Flow of pedestrians [p/min]** – number of pedestrians who in unit time, are moving in one direction pass on intersection on sidewalk
Security- lighting, overview and degree of activity of the path for the pedestrians	**Density of pedestrians [p/m^2]** – number of pedestrians who at a specific time are located on a specific part of the sidewalk
Economical- cost for pedestrians, primarily with the time lost during the journey	**Single pedestrian space [m^2/p] –** average space per pedestrian or reciprocal value of density

3. STATE-OF-THE-ART IN LEVEL OF SERVICE AND SPACE QUALITY FOR PEDESTRIANS

The quality walking space is secure, comfortable and attractive. The analysis for the LOS or the quality on the street environment for these users is equally complex as well as the analysis of the LOS for motor vehicles. That is, both the motor vehicles and the pedestrians are under large number of factors which belong to the driving environment and the structural environment.

It is believed that the methodology from the Transportation Research Board-TRB for the analysis of LOS is generally and technically the most superior. According to HCM (2000), the measure for pedestrian LOS is the single space expressed in m^2/pedestrian. Beside these the rest of the measures are defined, like: speed intensity and the relation flow/capacity [9, 15].

There are researches, for example the research from SCI from 1998 [13], which shows that the pedestrians value the LOS according to the side distance from the motor vehicles, flow and speed of the motor vehicles, type of motor vehicles (special, heavy vehicles) and the physical barrier which divides the motorized from the non motorized traffic (for example: street parking).

The model developed in 2000, again from SCI [14], is improved and is a result from multiple regression analysis on field collected data from 75 participants on the length of 24 sections on two-lane two-way urban streets. The speed of the sections is from 25 to 125 km/h, with 0-3% part from heavy vehicles. The analyzed sections had different geometric characteristics, the environmental characteristics were also different, the land use, the street greenery, as well as the street parking.

In their issue on HCM (2010), beside the remaining changes like multi modal approach towards the analysis on the LOS, the model for analysis of the pedestrian LOS is improved [16]. That is, large number of factors are taken into consideration which have influence on the space quality for the pedestrians: width of the traffic lane, width of the shoulders or the cyclist lane, into consideration is taken the street parking and the influence of the trees on the street, the width of the pedestrians path, the flow and speed from the motor vehicles [17].

In the software package ARTPLAN, the complex pedestrian LOS is simple because in the calculations are included only four input variables:

- side division of pedestrians from the motor traffic or division between the traffic lanes and the pedestrians path, described like insufficient, typically or desired, with preset values;
- the existence of obstacles which divides the pedestrian from the motor traffic, (trees, street parking and other elements);
- total width of the traffic lane (preset values);
- width of the shoulders or cyclist lane (preset values).

Craig et al., (2002) [2], described eighteen (18) elements which might influence on the quality of the environment of the motor vehicles, division of the pedestrians from the motor traffic, regulating the pedestrians and other objects.

Owen et al., (2004) [11], developed a list of even sixty (60) micro elements which influences the walking, example: existing continual walking paths, pedestrians crossings, regulated pedestrians areas (benches, garbage bins, lighting, informational boards), land usage, types and speed of motor vehicles and so on.

According to research from Devin (2008) [3], a highly quality and safe environment for walking is in strong relation with aesthetic quality and design, where as Bloomberg, Burden (2006) [1], in the procedure for calculation of the pedestrians level of service includes also urban equipment (benches, garbage bins, plants pots, signs and so on).

In year 2006 Federal Highway Administration developed the model Shared-Use Path LOS – SUPLOS, which represents a mathematical formula for confirming the level of service which different users (different categories pedestrians, different categories cyclist, and others), feel it while moving and traveling along the same path. The model is based on detailed research, through series of video recordings.

4. STATE-OF-THE-ART IN PEDESTRIAN MOVEMENT MODELING

The modeling movement by pedestrians is a subject for studying for more than four decades. The methods used during the analysis are concluded by direct observations, photography and recordings, while the main aims for whom the studies are done were towards development on concepts for pedestrians level of service analysis, determining project elements for the pedestrians objects or planning towards pedestrians paths on the pedestrians flows. In the last twenty years have been developed more complex microscopic and stochastic models for pedestrians movement.

In the procedures for pedestrians movement modeling usually is recommended two main principles:

a) Not to allow conflict between the pedestrians, equipment on the street and the remaining participants in the traffic flow;
b) To ensure adequate surface for safe and comfortable flow of the pedestrians (sidewalk or crossing);

Implementing the research study, seven basic conclusions are drawn:

1. The pedestrians show strong aversion towards the change of the walking direction. Subsequently, the pedestrians choose the shorter path for movement.
2. The pedestrians chose to move with their individual speed. In terms of medium and high densities the pedestrians flows have a lot of similarities and are compared with the flows of gases and fluids. In conditions of extremely high densities pedestrians spontaneously are organized in rows one behind the other.
3. According to Henderson (1974) [5], the speed of an average pedestrian with height of h_p=1.75m, weight m_p=75 kg and maximal diameter of the body from d_p=0.45 m is normally distributed with middle value from v_p=1.34m/s or v_p=4.83km/h and standard deviation of $\sigma v_p =$0.26 m/s (19.3%), that which corresponds on the maximal density of 6.6 pedestrians/m^2.

   The average time of following among the pedestrians is 2 (s). The same source confirmed that under density of 3.0 persetrians/m^2 the physical contact among them is inevitable.
4. According to Helbing (2001) [16], when a group of pedestrians who move on the sidewalk or the pathways are analyzed, they are generated according to the normal distribution in the time interval of monitoring between them distributed according to Puasov’s distribution. According to him the dynamical equation of movement of the pedestrians depends on the speed of the pedestrian at the moment (known as behavioral force or social force) and the position of the pedestrian at the time *t*.

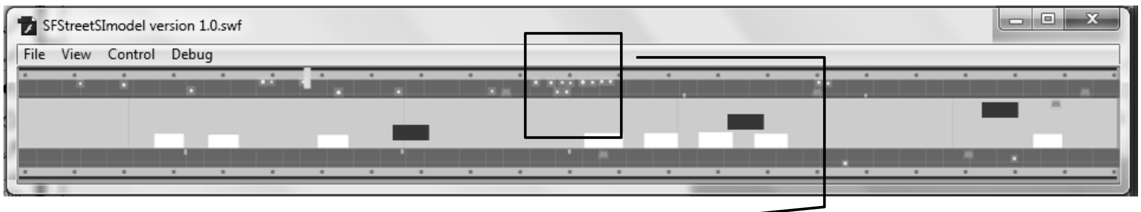
5. The pedestrians, keeps a certain distance in relation to the remaining pedestrians and the objects around them, [9].
6. Average pedestrian in normal weather conditions and under daylight might be noticed at a distance from 100 – 200m, [8].
7. Kwon Y., Morichi S. and Yai T. [8], suggested index of time and space occupation on the street with small width from the side of the pedestrians, cyclist and vehicles.

5. SFStreetSIModel version 1.0: MODELING OF PEDESTRIAN MOVEMENT ON LOW SPEED URBAN STREET SIDEWALK

SFStreetSIModel, version 1.0 (Side Friction Street SImulation Model) is microscopic simulation model made in programming language Action Script 3, implimented in Adobe Flash and Adobe Flex technology. SFStreetSIModel, version 1.0 simulates movement of vehicles and pedestrians on two-lane two-way section on low speed urban street under the influence of elements which form a condition known as side friction. During simulation pedestrians are approximated with yellow circles, moving from sidewalk side to side within the clear width and time headways distributed according to the negative exponential distribution.

Sidewalk width has been modeled according to the land use, from 1.5 to 2.0 m, and it contains:

- Edge: closest to the street pavement;
- Furnishing zone: garbage containers, portable advertising boards, and
- Clear zone or throughway: effective space available for pedestrian travel.



Legend:

 pedestrian moving on sidewalk into the two directions

Fig. 1. SFStreetSIModel version 1.0 – sidewalk and pedestrian visualization
Rys. 1. SFStreetSIModel version 1.0 – wizualizacja chodnika i pieszych

The condition of the pedestrian (p) at the moment (t) - P(p).(t), is described in the following vector condition:

$$P_{c,p,s} = [\, P_{c,p,s}.X, P_{c,p,s}.V, P_{c,p,s}.a, P_{c,p,s}.opr]^{tr} \quad (1)$$

P(p).X(t)...... position of pedestrian (p) at the moment (t) in the relation to the generator
P(p).V(t)...... pedestrian speed at the moment (t)
P(p).a(t)....... acceleration of the pedestrian (p) at the moment (t)
P(p).opr(t)... decision for change of direction by the pedestrian (p) at the moment(t)
c = 1,2......... sidewalk from which the movement of the pedestrian is observed
1... from the side of the traffic lane 1 (down sidewalk);
2... from the side of the traffic lane 2 (up sidewalk);
p = 1,2....P_c.. number of pedestrians on the side walk;
s = 1,2.......... directions of movement by the pedestrians
1... in the direction of movement of vehicles on a traffic lane 1 (left to right);
2... in the direction of movement of vehicles on a traffic lane 2 (right to left);

The condition of the pedestrian (p) at the moment (t+dt) depends on:

- its condition at the moment (t+dt) **-** P1(p).(t+dt);
- the condition of the pedestrian before him (p-1) **-** P1(p-1).(t+dt);
- the condition of the pedestrian who he passes by P2(p).(t+dt);
- the distance from the street furniture.

The attributes of the pedestrians are shown with the following vector:

$$Pa_{c,p,s} = [\, P_{c,p,s}.hp, P_{c,p,s}.dp, P_{c,p,s}.V_p, P_{c,p,s}.m_p \,]^{tr} \quad (2)$$

P(p).h_p........hight of pedestrian (p)
P(p).d_p........diameter of the pedestrian's body (p)
P(p).V_p........speed of the pedestrian (p)
P(p).m_p........mass of the pedestrian (p)

Pedestrian path of movement is determined with certain restrictions: they keep min 0.30 m when pass each other, min 0.35 m from the on-street parked vehicles, min 0.35 m from the carriageway, and min 0.30 m from the portable advertising boards, trees and garbage containers.

The level of service of the pedestrians has been calculated as pedestrians on square meter in 15 minutes, or number of pedestrians who at a specific time are located on a specific part of the sidewalk, shown on Fig.2.

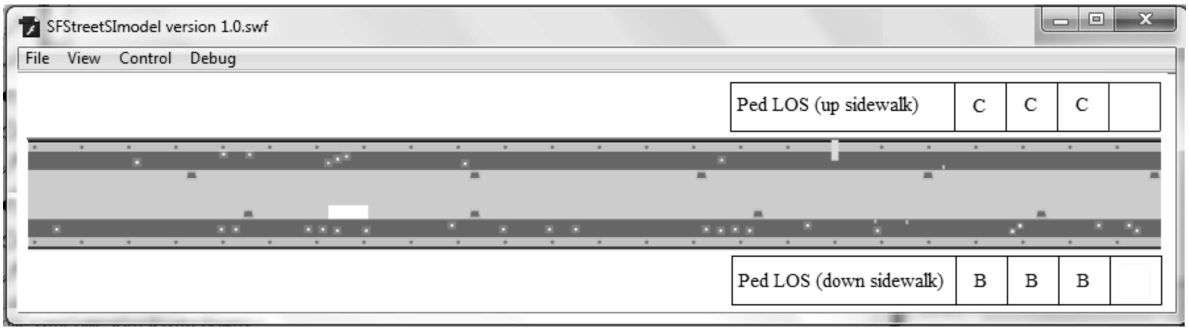


Fig. 2. SFStreetSIModel version 1.0 – pedestrian sidewalk LOS visualization
Rys. 2. SFStreetSIModel version 1.0 – wizualizacja utwierdzonego poziomu usługi dla pieszych na chodniku

The algorithms of the initialization, modeling and simulation of pedestrian movement in SFStreetSIModel, version 1.0, are presented in Fig. 3 - Fig. 5.

6. CONCLUSION

Thoughtfully designed sidewalks can create inviting places in which pedestrians want to walk while feeling secure and safe. Namely, the principles of Crime Prevention through Environmental Design must be applied to the design and retrofit of public spaces. The urban environment can appeal to pedestrians and encourage social interaction by offering different views, ambiance and appropriate spaces for resting and walking.

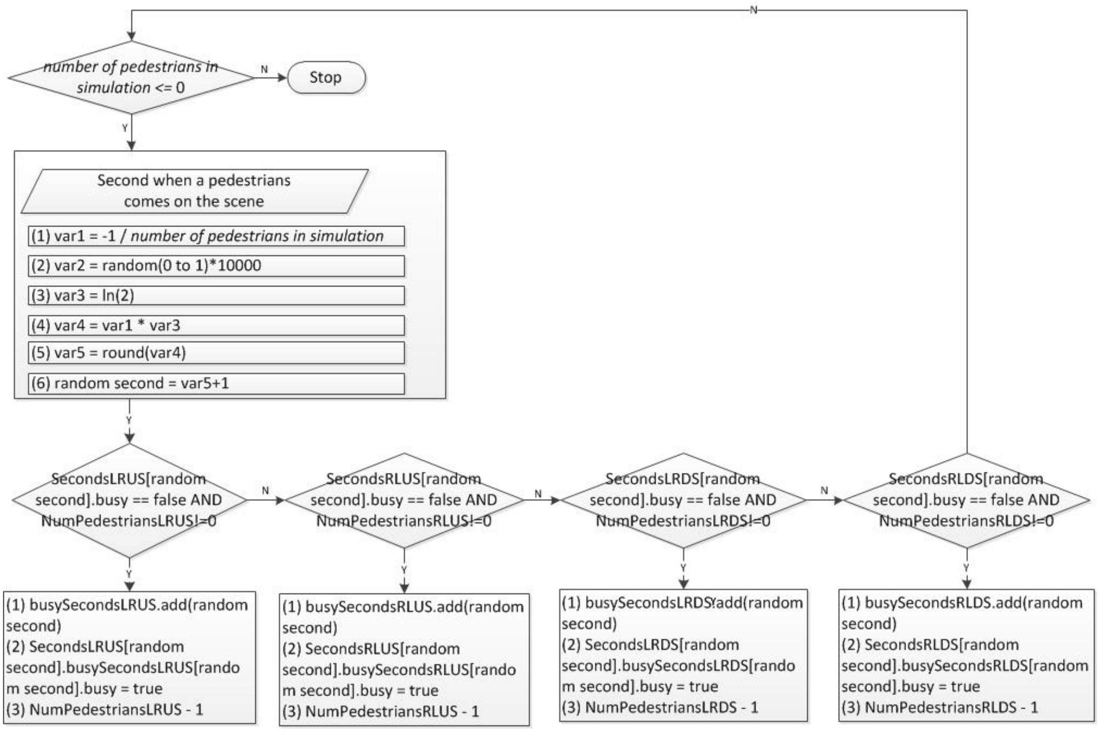


Fig. 3. SFStreetSIModel version 1.0 – pedestrians initialization
Rys. 3. SFStreetSIModel version 1.0 – inicjalizacja pieszych

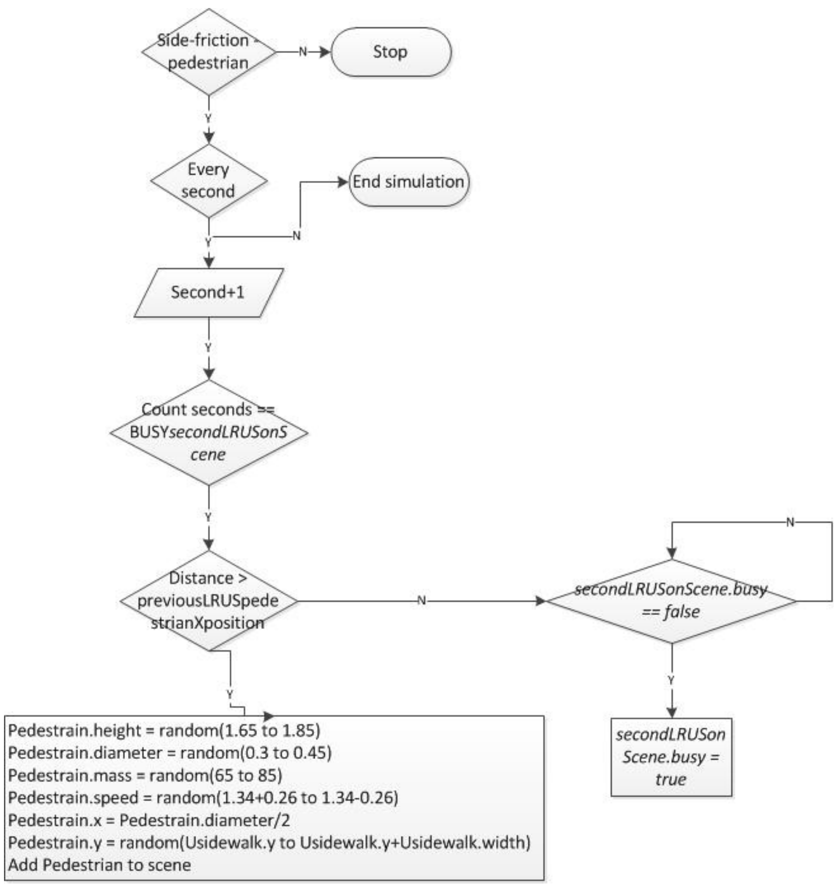


Fig. 4. SFStreetSIModel version 1.0 – pedestrians distribution on sidewalks
Rys. 4. SFStreetSIModel version 1.0 – rozkład pieszych

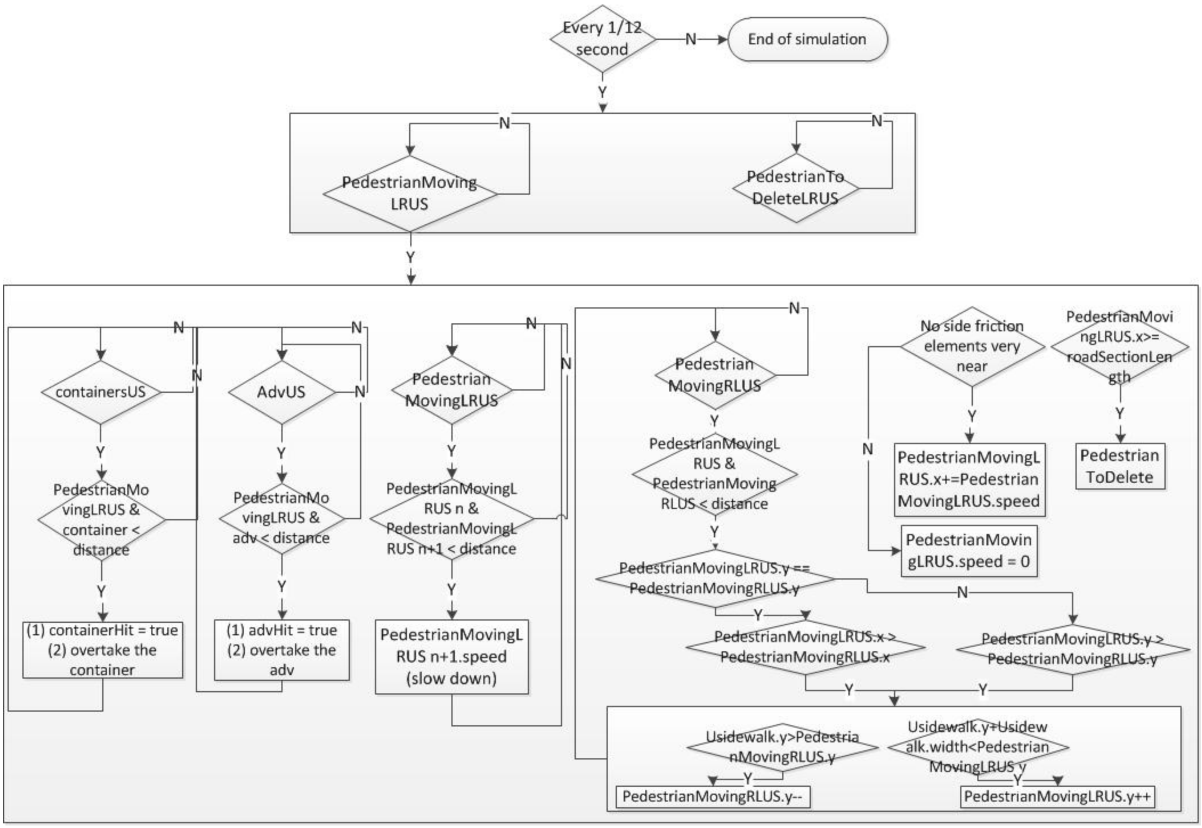


Fig. 5. SFStreetSIModel version 1.0 – pedestrian movement modeling and simulation
Rys. 5. SFStreetSIModel version 1.0 – modelowanie i symulacja ruchu pieszych

One of our main purposes while developing SFStreet SIModel, version 1.0, was to analyze how sidewalk design affects pedestrian operations and level of quality on low speed urban streets in which walking needs to be a meaningful transportation choice for efficient and healthy social and economic urban interaction. In this article we present the process of modeling and simulation of the movement of pedestrians on the sidewalks. Their condition, preferences and their attributes, and the ability of the model to determine the level of service for pedestrians. For the analysis on three residential streets with different width of the carriageway we made a significant number of simulations, calibrated with terrain data. Relatively unsafe and non comfortable level of service for pedestrians on residential streets was found, between C and E.

Therefore, we recommend that particular attention needs to be given to the sidewalk design, traffic calming measures and to encourage the establishment of safe and lively urban spaces.

Bibliography

1. Bloomberg M., Burden A.: *Pedestrian Level of Service Study Phase I*. NYC DCP, 2006.
2. Craig et al.: *Exploring the effect of the environment on physical activity: A study examining wolking to work*. American Journal of Preventive Medicine, 23 (2S), 2000, p.36-43.
3. Devin A.: *Measuring the Quality of the Pedestrian Environment: Towards an appropriate assessment methodology*. School of Community and Regional Planning, The University of British Columbia, 2008.
4. DUMAS, *Work Package 6: Safety for pedestrians and two-wheelers*. Danish Road Directorate, Copenhagen, Denmark, 1998.

5. Henderson F.: *On the fluid mechanics of human crowd motion*. Transportation Research 8, 1974, p.509-515.
6. Helbing D.: *Self-organizing pedestrian movement.* Environment and Planning B: Planning and Design 2001, volume 28, 2001, p.361-383.
7. Helbing, D.: *A mathematical model for the behavior of pedestrians.* Behavioral Science 36, 1991, p.298-310.
8. Kwon Y., Morichi S., Yai T.: *Analysis of Pedestrian Behavior and Planning Guidelines with Mixed Traffic for Narrow Urban Streets*. Paper No. 98-0541, Transportation Research Record 1636, 1998.
9. Kuzović Lj.: *Kapacitet i nivo usluge drumskih saobraćajnica*. Saobraćajni fakultet Univerziteta u Beogradu, Beograd, 2000, p.321-324.
10. MASTER, *Final report*. VTT, Finland, 1998.
11. Owen et al.: *Understanding environmental influences on walking: Review and research agenda*. American Journal of Preventive Medicine, 27 (1), 2004, p.67-76.
12. PROMISING, SWOV Institute for Road Safety Research, Leidschendam, Netherlands, 2001.
13. Sprinkle Consulting Inc., *Level of Service Methodology: The Roadside Pedestrian Environment*. Lutz, Florida, 1998.
14. Sprinkle Consulting Inc., *Modeling the Roadside Walking Environment: A Pedestrian Level of Service*. Lutz, Florida, 2001.
15. Transportation Research Board, *Highway Capacity Manual*, Washington, D.C., 2000.
16. Transportation Research Board, *Highway Capacity Manual*, Washington, D.C., 2010.
17. Vandehey M., Wright S.: *Overview of the 2010 HCM*. Transportation Education Series, 2009.
18. WALCYNG, Department of Traffic Planning and Engineering, Lund University, Sweden, 1998.

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