Accident Analysis and Prevention 92 (2016) 139–152

Contents lists available at ScienceDirect

Accident Analysis and Prevention

journal homepage: www.elsevier.com/locate/aap

Towards an integrated approach of pedestrian behaviour and exposure

Eleonora Papadimitriou*

National Technical University of Athens, Department of Transportation Planning and Engineering, Greece

ARTICLE INFO

Article history:
Received 20 October 2015
Received in revised form 22 March 2016
Accepted 23 March 2016
Available online 8 April 2016

Keywords:
Pedestrian
Behaviour
Exposure
Field survey
Questionnaire
ICLV models

ABSTRACT

In this paper, an integrated methodology for the analysis of pedestrian behaviour and exposure is proposed, allowing to identify and quantify the effect of pedestrian behaviour, road and traffic characteristics on pedestrian risk exposure, for each pedestrian and for populations of pedestrians. The paper builds on existing research on pedestrian exposure, namely the Routledge microscopic indicator, proposes adjustments to take into account road, traffic and human factors and extends the use of this indicator on area-wide level. Moreover, this paper uses integrated choice and latent variables (ICLV) models of pedestrian behaviour, taking into account road, traffic and human factors. Finally, a methodology is proposed for the integrated estimation of pedestrian behaviour and exposure on the basis of road, traffic and human factors. The method is tested with data from a field survey in Athens, Greece, which used pedestrian behaviour observations as well as a questionnaire on human factors of pedestrian behaviour. The data were used (i) to develop ICLV models of pedestrian behaviour and (ii) to estimate the behaviour and exposure of pedestrians for different road, traffic and behavioural scenarios. The results suggest that both pedestrian behaviour and exposure are largely defined by a small number of factors: road type, traffic volume and pedestrian risk-taking. The probability for risk-taking behaviour and the related exposure decrease in less demanding road and traffic environments. A synthesis of the results allows to enhance the understanding of the interactions between behaviour and exposure of pedestrians and to identify conditions of increased risk exposure. These conditions include principal urban arterials (where risk-taking behaviour is low but the related exposure is very high) and minor arterials (where risk-taking behaviour is more frequent, and the related exposure is still high). A "paradox" of increased risk-taking behaviour of pedestrians with low exposure is found, suggesting that these pedestrians may partly compensate in moderate traffic conditions due to their increased walking speed.

1. Background and objectives

Despite the strong focus of pedestrian research on behavioural aspects, the link between pedestrian behaviour and safety has not been adequately explored (Papadimitriou et al., 2012). Moreover, despite the increasing concerns on the improvement of pedestrian safety (OECD, 2011), the dedicated studies on pedestrian exposure and risk are mostly dated ones.

In these older studies, two main approaches are identified for the estimation of pedestrian exposure in urban areas: (i) the macroscopic approach, in which population exposure is estimated in terms of number of pedestrians (OECD, 1998), number of trips (Jonah and Engel, 1983), distance walked (Baltes, 1998) or time spent in traffic (Lee and Abdel-Aty, 2005), with main purpose the estimation of risk rates (i.e. as the number of accidents or casualties per the amount of exposure), and (ii) the microscopic approach, in which individual exposure is estimated in terms of traffic conflicts (Gårder, 1989), such as the number of road crossings per time or distance unit (Howarth, 1982; Keall, 1992; Leden, 2002), possibly in conjunction with road and traffic conditions (Van der Molen, 1981; Cameron, 1982), which is seldom translated into concrete risk estimates.

In two recent studies, a framework for microscopic analysis of pedestrian exposure has been provided, and it has been further demonstrated how the crossing behaviour of pedestrians can be a key aspect of exposure. More specifically, Lassarre et al. (2007) revisited a microscopic exposure indicator proposed by Routledge et al. (1974, 1976), implemented some adjustments for the improvement of the indicator and pilot-tested an application of this indicator for the estimation of exposure for different crossing behaviours through a basic discrete choice model. Papadimitriou

* Correspondence address: Department of Transportation Planning and Engineering, National Technical University of Athens, 5 Heroon Polytechniou Str., GR-15773 Athens, Greece.
E-mail address: nopapadi@central.ntua.gr

http://dx.doi.org/10.1016/j.aap.2016.03.022
0001-4575/

et al. (2012) presented an improved application, by means of combining the 'adapted' Routledge indicator with crossing behaviour data from a more robust and accurate sequential choice model. These studies were successful in demonstrating a link between pedestrian behaviour and exposure, as it was shown that pedestrian choices directly affect the exposure estimates at different road and traffic conditions; however they did not take into account the human factors related to pedestrian behaviour. Moreover, they were limited to individual exposure estimates.

Human factors of pedestrian behaviour have been largely examined on the basis of the theory of planned behaviour (e.g. Evans and Norman, 1998; Diaz, 2002; Bernhoft and Carstensen, 2008) and other formal tools such as questionnaires (Sisiopiku and Akin, 2003; Granié et al., 2013), in-depth interviews (Hine, 1996) etc. These studies contribute to the understanding of pedestrians attitudes, perceptions and motivations, and the resulting declared preferences and observed behaviour, and less so to the identification of concrete road accident risk implications. Similarly, road and traffic factors of pedestrian behaviour and safety, although having received more attention in the literature (for complete reviews see Ishaque and Noland, 2007; Papadimitriou et al., 2009), are seldom combined with human factors. A recent study (Papadimitriou et al., 2016a) developed integrated models of road, traffic and human factors of pedestrian crossing choices.

In this framework, this paper proposes an integrated methodology for the analysis of pedestrian behaviour and exposure in urban areas. The research builds on existing recent studies, uses data from a survey combining field observations and questionnaire responses, develops new ICLV models and further develops microscopic exposure indicators, to address three research challenges: (i) to identify and quantify the combined effect of road, traffic and human factors on pedestrian behaviour and exposure, (ii) to establish the link between pedestrian behaviour and exposure in light of the effects of road, traffic and human factors, (iii) to enable integrated estimation of behaviour and exposure for each pedestrian and for a population of pedestrians.

The paper is structured as follows: in Section 2 the research hypotheses are presented as per the effects of road, traffic and human factors on pedestrian behaviour and exposure. In Section 3, the research methodology is presented, including methods for the estimation of pedestrian exposure in different conditions, methods for the estimation of integrated pedestrian choice models, and description of the field survey carried out in Athens, Greece for the implementation of the proposed methods. Section 4 includes the results of this research, in terms of the choice models developed and the estimation of pedestrian behaviour and exposure for different road, traffic and human factors scenarios, for individual pedestrians and for a population of pedestrians. In Section 6, a synthesis of the results is carried out, allowing to enhance the understanding of the interactions between behaviour and exposure of pedestrians and to identify conditions of increased risk exposure. The paper concludes and proposes some next steps in Section 7.

2. Research hypotheses: road, traffic and human factors in exposure

The present research is based on two main research hypotheses: (i) road, traffic and human factors affect both pedestrian crossing behaviour and pedestrian exposure (although not necessarily in a similar manner), and (ii) pedestrian behaviour and exposure are linked, i.e. the exposure of pedestrians is affected by their behavioural choices.

The specific research hypotheses tested in this paper are as follows:

- Effect of road type on behaviour: in collector/residential roads, due to the lack of constraints and of vehicle-pedestrian interaction, pedestrians are more likely to cross at mid-block or diagonally, in order to minimise the trajectory length. On principal urban arterials, on the other hand, the constraints are such (traffic, speed of traffic, number of lanes etc.) that all pedestrians will opt for a protected 'exclusive' crossing at signalized junction. In a mixed urban area (e.g. minor arterial roads), more variation is expected in pedestrian crossing behaviour.
- Effect of traffic on behaviour: when there is no traffic, pedestrians will choose the shortest path (e.g. cross at mid-block or diagonally). At high traffic there is increased probability of seeking for a protected crossing at junction. At congestion, pedestrians are also likely to cross at midblock or diagonally, in between stopped vehicles.
- Effect of human factors on behaviour: underlying factors such as risk-taking, conformity and the tendency to optimise the trip are correlated with crossing decisions.
- Effect of road type on exposure: Pedestrians exposure is higher on principal arterial roads, lower on minor arterial roads, and very low on collector/residential roads. The number of lanes affects exposure, as having to cross multiple lanes is more complicated than crossing a single lane. Crossing a divided road, on the other hand, may be considered equivalent to crossing two individual roads, as the pedestrian will make a separate crossing decision while standing on the median/refuge island etc. The use of a protected 'exclusive' pedestrian signal control phase (i.e. green/walk light for pedestrians) directly corresponds to a situation of no interaction with traffic, resulting in practically zero risk exposure. A violation of pedestrian signal corresponds to an uncontrolled crossing situation, in which pedestrians negotiate the incoming traffic stream.
- Effect of traffic on exposure: When traffic is low, traffic gaps are larger, although vehicles speed may be increased. When traffic increases, pedestrian exposure initially increases, as traffic gaps are smaller. In high traffic conditions, however, exposure decreases, because vehicle speed decreases. In traffic congestion, pedestrians may cross in between stopped vehicles and practically suffer zero risk exposure.
- Effect of human factors on exposure: Low risk perception, risk-taking tendency, walking motivations etc. are related to the probability of crossing at mid-block, which in turn results in increased exposure. However, more risk-taking pedestrians may also walk at increased speed, partly compensating for their increased exposure.

3. Methodology

3.1. Estimation of pedestrian exposure

3.1.1. The adapted Routledge indicator

Recent research (Lassarre et al., 2007) demonstrated that the Routledge indicator allows the assessment of pedestrians exposure while road crossing in isolated locations with different road and traffic characteristics, and can be further combined with pedestrian crossing behaviour information at the examined locations. The original Routledge indicator (Routledge et al., 1974, 1976) provides an estimate of pedestrian exposure while crossing a single road lane at a mid-block unsignalised location, in relation to vehicle length and speed, pedestrian speed and crossing width, as follows:

$$R = \frac{l + vt_c}{d} \quad (1)$$

where R is the risk exposure of road crossing, l is the mean length of vehicles, v is the mean traffic speed, t_c is the pedestrian's time taken to cross and d is the mean vehicle headspace. As mentioned