Analysis of Pedestrian Risk Exposure in Relation to Crossing Behaviour

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Abstract

The objective of this research is the analysis of pedestrians risk exposure along urban trips in relation to pedestrians crossing behavior. First, an appropriate microscopic indicator is selected for the estimation of pedestrians risk exposure while road crossing at isolated locations. This indicator expresses exposure as the number of vehicles encountered by pedestrians during the crossing of a single uncontrolled road lane, and can be further adapted and applied for various road design and traffic control features. Moreover, the number and type of crossings along a pedestrian trip can be identified on the basis of the trip length and topology, whereas the choice set of alternative crossing locations for each crossing decision can also be defined. The crossing probability associated with each alternative location along the trip can be then estimated by means of a sequential logit model. Finally, a method is presented for the estimation of pedestrians exposure along a trip in relation to their crossing behaviour. The proposed approach is demonstrated on the basis of a pilot implementation, for a typical pedestrian trip in the centre of Athens, Greece, for four scenarios combining different traffic conditions and pedestrians' walking speed. The results show that pedestrians' exposure along a trip is significantly affected by their crossing choices, as well as by road and traffic characteristics. It is also revealed that pedestrians with increased walking speed may partly compensate for their risk exposure, so that it is not significantly affected by traffic volume. Moreover, specific locations with increased pedestrian risk exposure can be identified for each trip. The proposed microscopic analysis of pedestrian exposure is proved to be advantageous compared to existing macroscopic ones, revealing the different possible definitions and aspects of pedestrians exposure, with useful implications for road safety analysis.

Background & Objectives

- The majority of pedestrian casualties in road crashes occurs while road crossing, where pedestrians interact with motorized traffic.
- The analysis of pedestrians risk exposure while road crossing along urban trips may contribute towards more efficient and pedestrian-oriented planning and implementation of road design, traffic control and crossing facilities, the more accurate estimation of pedestrians crash risk.
- Existing pedestrian exposure indicators are macroscopic and cannot be applied for isolated locations or individual pedestrians. The interaction between pedestrians and vehicles is not sufficiently taken into account.
- Existing models of pedestrian crossing behaviour concern local level behaviour and can not be applied at trip level.

Objectives

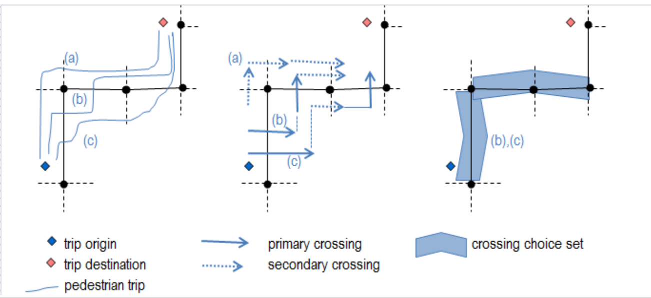
The objective of the present research is the analysis of pedestrians risk exposure along entire trips in urban areas in relation to crossing behavior.

Methodology

Topological analysis of pedestrian trips and crossings

On the basis of recent research (Lassarre et al. 2007; Papadimitriou et al. 2010; Papadimitriou, 2012):

- The topology of the road network is described by a graph with links and nodes, and the origin and the destination of a pedestrian trip are located on the graph neighborhood.
- The location of certain crossing movements along a trip is stochastic (primary crossings), whereas the locations of other crossing movements are deterministic (secondary crossings).
- The analysis of pedestrians crossing behavior may focus on primary crossings only.
- The total number of primary crossings along a trip can be estimated on the basis of the Jordan Curve theorem of topology (e.g. certain trip topologies correspond to odd number of primary crossings, other trip topologies correspond to even number of primary crossings).
- The choice set of alternative crossing locations for each primary crossing is finite and can be determined on the basis of topological and other criteria.



- If trip (a) is opted for, three secondary crossings at deterministic locations are expected.
- If either trip (b) or (c) is opted for, two primary crossings at stochastic locations are expected (i.e. one somewhere along the first link and one somewhere along the second or third link).
- In trips (b) and (c), a secondary crossing of the secondary road between links 2 and 3 will be made; its location (i.e. on which side of the graph this will take place) is known once the location of the second primary crossing is determined
- The crossing choice sets for trips (b) and (c) are thus finite (see right panel).

Primary crossing probabilities $P<1$, with $\Sigma P=1$ in a finite choice set
Secondary crossing probabilities $P=1$, once primary crossing locations are known

Methodology (cont.)

Microscopic Indicator of Pedestrian Exposure for Crossing at Isolated Locations

- An appropriate pedestrians' exposure indicator is selected, namely the Routledge indicator (Routledge et al. 1974), as improved by Lassarre et al. (2007), which will be refered to as the 'adapted Routledge indicator'.

1.

$$R = \frac{l + vt_c}{d}$$

$$v = v_f\left(1 + \frac{k}{k_j}\right)$$

$$q = kv$$

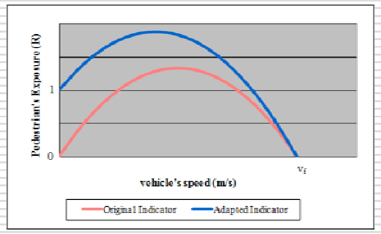
$k=1/d$ & $k_j=1/l$

2.

$$R = \frac{k}{k_j} + q t_c$$

3.

$$R = q t_c$$



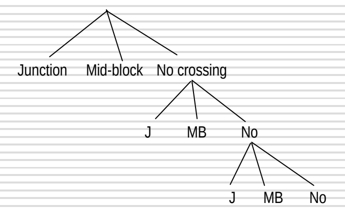
1. The original Routledge indicator expresses the proportion of space unavailable to pedestrians for crossing, i.e. the proportion of space occupied by vehicles. This proportion is the ratio of the vehicle length (l), plus the distance covered by the vehicle during the pedestrian crossing movement (vt_c), to the total space available between moving vehicles (d).
2. The original indicator was rewritten as a result of a transformation on the basis of fundamental traffic flow relationships. The indicator now comprises a static part (the ratio of the two densities k/k_j), and a dynamic part (the number of vehicles encountered during the crossing qt_c). Exposure R=0 at free flow conditions and R>1 at high densities and towards congestion. Values higher than 1, where the spaces occupied by moving vehicles overlap and no space is available for pedestrians, are attained rather quickly.
3. Lassarre et al. (2007) note that increased traffic density results in decreased vehicle speed and consequently crossing opportunities, although limited, may still exist. It is suggested to delete the static part of the indicator, resulting in the adapted indicator.

Modelling Pedestrian Crossing Behaviour along Entire Trips

- The choice of crossing location among the alternatives of the choice set can be modeled with discrete choice models
- Two hypotheses have been examined: a sequential choice process and a hierarchical choice process.
- The hierarchical choice process assumes that the pedestrian considers the entire set hierarchically, by first selecting a road link among the available alternatives (marginal choice), and then a specific location, either at junction or at mid-block within that link (conditional choice) → multinomial nested or cross-nested logit models.
- The sequential choice process assumed that a pedestrian examines the available choice set sequentially, by making a separate crossing decision on each link of the choice set → sequential multinomial or nested logit models.
- Both approaches were tested with data from a field survey in Athens, Greece, in which pedestrian trips were recorded in real time using a video camera. Survey participants were selected with simple random sampling from the exits of metro stations (491 pedestrian trips, including 2.418 road links, 884 primary road crossings, and 52 variables per trip).

Utility functions

U_0 - Cross at Mid-block =	- 0.140 + 0.614 * first + 0.769 * skip1 + 0.061 * skip2 - 0.526 * L_changedirend - 0.569 * l_logvped2 + 0.441 * L_trafficL + 1.660 * L_plength
U_1 - Cross at Junction =	- 0.183 + 0.614 * first + 0.769 * skip1 + 0.061 * skip2 - 0.569 * l_logvped2 + 0.641 * J_signal + - 0.633 * L_lanes2 + 1.660 * L_plength
U_2 - No Crossing =	0.000
Model:	Multinomial Logit
Number of observations:	680
Likelihood ratio test:	216.207
Estimated parameters:	12



The best fitting model of pedestrian crossing behaviour along a trip is a sequential logit model with variables controlling for state-dependence

- A change of trip direction (L_changedirend) increases the probability of crossing at junction
- Increased probability of crossing at the first road link of each choice set (first). Having skipped one or two crossing opportunities increases the utility of crossing (skip1, skip2).
- An increase of the percentage of the trip length increases the utility of crossing (L_plength).
- Crossing utility decreases with pedestrian walking speed (l_logvped) (i.e. faster pedestrians postpone crossing).
- Traffic signals increase the utility of crossing at junction (J_signal).
- Low traffic volume increases the utility of crossing at mid-block (L_trafficL).
- The presence of two lanes (L_lanes2) reduces the probability of crossing at junction compared to the presence of one lane.

Pedestrians' Exposure in Relation to Crossing Behaviour

- The adapted Routledge indicator estimates pedestrian risk exposure (R_i) for crossing a road at an isolated location. The risk exposure implied by the adapted Routledge indicator is independent from the crossing probability, which is taken equal to 1.
- The sequential logit model developed estimates the probability (P_i) of crossing at each location within the pedestrians choice sets along a trip.
- When a crossing location is included in one of the choice sets of the primary crossings that will be carried out along the trip, a crossing probability lower than one corresponds to that location. In this case, the actual pedestrians exposure (R') for the examined location within the specific trip will be lower than the theoretical one (R). Therefore, for each location (i) along a pedestrian trip:

$$R'_i = R_i * P_i$$

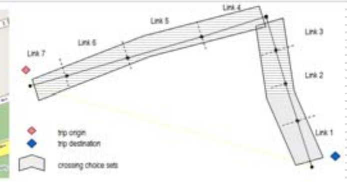
- For the entire trip, the total risk exposure of pedestrians is estimated as the weighted mean of the exposure at all the (n) alternative crossing locations along a trip in relation to the related crossing probabilities:

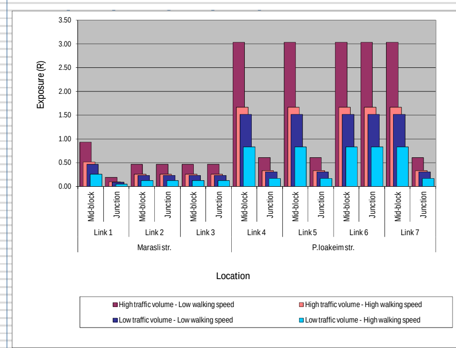
$$R = \sum_{i=1}^{n} R_i * P_i$$

A different definition of pedestrian exposure while road crossing is thus formulated in relation to the crossing probability

Implementation

- Typical trip in the centre of Athens
- Four scenarios:
  - High traffic volume / low walking speed
  - Low traffic volume / high walking speed
  - High traffic volume / low walking speed
  - High traffic volume / high walking speed





...dless of crossing behaviour

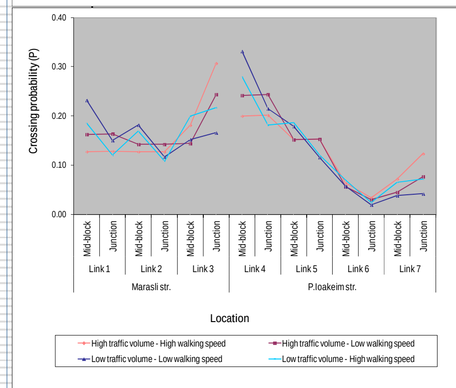
..., due to increased number of lanes and the increased traffic, both at peak and off-

...lking speed and high traffic volume.
...fferent between 'high traffic volume - high walking speed' and 'low traffic volume -

...ties along the trip

...e set
... beginning, and partly towards the end of each choice set at increased traffic

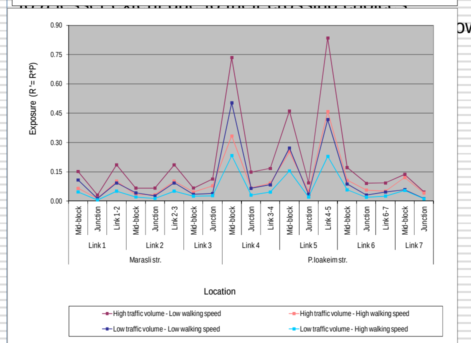
...g (less pronounced along P.Ioakeim st., where the road and traffic environment is
...ontrolled locations.
...t junction when the traffic volume is low on Marasli st.
...high traffic volume on P.Ioakeim st.
... Marasli - P.Ioakeim junction (i.e. Link 3- Link 4).



... the trip in relation to crossing behaviour

... and decreases with walking speed
...d at the Marasli-P.Ioakeim junction, where the change of trip direction occurs, and
...he two primary crossings in that junction area.
...sed, primarily because of the increased time of their interaction with vehicles, and

...ow, except between Links 4 and 5 (the only non-signalised junction on the busy



Conclusions

- The present research addressed a number of conceptual and methodological issues involved in the analysis of pedestrians risk exposure in urban areas, focusing on the further refinement of microscopic exposure indicators, their adjustment from local level to trip level, and the use of crossing behaviour data at trip level.
- A notion of 'variable risk exposure' of each location of the road network is outlined. Although a location of the road network is theoretically associated with a given risk exposure, regardless of the crossing probability at this location, the actual risk exposure of a pedestrian at this location within a specific trip is different from (i.e. lower than or equal to) the theoretical one, on the basis of the crossing probability at this location.
- Although the shape of the distribution of pedestrians' risk exposure along a trip may be similar in different scenarios, the magnitude of the changes in risk exposure from changes in road and traffic conditions and pedestrian crossing behaviour, may be important.
- In the proposed approach, a much finer distribution of pedestrian exposure along the trip is obtained; The whole approach is generic and can be applied for the analysis of any pedestrian trip in urban areas.
- The results reveal a group of crucial parameters, which are common in the description of both pedestrians crossing behaviour and pedestrians exposure while road crossing, namely the road width, the traffic volume, the walking speed and the traffic signals.

Key references

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