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Summary of the Ph.D. Thesis titled

"Modelling pedestrians' behaviour and safety in urban areas"

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The objective of this Ph.D. Thesis is the **development of models for the observed behaviour of pedestrians as regards road crossing along entire trips in urban areas, and the estimation of their accident risk exposure**, as a result of this behaviour. In particular, a generic methodology is developed for determining pedestrians' behaviour and risk exposure at any location along any urban trip.

The review of the literature on pedestrians' behaviour and safety revealed that existing pedestrian crossing behaviour models in urban areas mainly concern local level analyses, whereas **crossing behaviour along entire trips** has not been examined. Moreover, pedestrians' risk exposure is mainly estimated by means of macroscopic indicators over a population of pedestrians, and these indicators do not take into account the behaviour of pedestrians and their interaction with vehicles during road crossing. From the existing research, a need for further research on pedestrians' behaviour and safety as regards road crossing in urban areas is identified, allowing for a better understanding of pedestrians' decision making processes and a more accurate estimation of their accident risk exposure.

For the **mathematical parameterisation of pedestrians' road crossing behaviour** along a trip, a topological consideration of the urban road network and of pedestrian trips was opted for, leading to the identification of several basic properties of pedestrian trips and road crossings. In particular, it was proved that certain crossings are stochastic (primary crossings), whereas other crossings are deterministic (secondary crossings), and consequently the analysis may focus on primary crossings only. Moreover, the shortest perceived trip path can be defined, leading to the identification of a systematic relationship between consecutive primary crossings and the sections of the trip corresponding to the choice set of each primary crossing.

According to the above, an **algorithm for determining the choice set** of each primary crossing along a pedestrian trip is developed. Furthermore, the choice of crossing location among the available alternatives is modelled by means of discrete choice models. Different hypotheses are examined as regards the pedestrians' decision making process, namely a sequential choice process and a hierarchical choice process. Moreover, for the estimation of pedestrians risk exposure along a trip, the use of a microscopic exposure indicator is proposed; this indicator expresses the possibility to cross in relation to traffic volume, speed and crossing distance.

For the implementation of the above methodology, a **field survey** was carried out, in which pedestrian trips in urban areas were recorded in real time and in motion using a video camera. The selection of survey participants was carried out by means of simple random sampling from the exits of metro stations in the centre of Athens. In total, 491 pedestrian trips were recorded, including 2.418 road links and 884 primary road crossings. For each trip a total of 52 variables were collected, concerning characteristics of the pedestrians (age, gender, speed etc.), of the trip (length, duration, origin, destination etc.), of the road links (number of directions, number of lanes, shoulder width, roadside parking, traffic volume, traffic signals etc.) and of the road crossing (location, type etc.).

Furthermore, a detailed **matching of different types of discrete choice models to specific behavioural hypotheses** for pedestrians was carried out. In the framework of a sequential decision making process hypothesis, different models were developed (sequential multinomial logit, sequential nested logit, mixed logit with random heterogeneity), while the dynamics of sequential decisions were taken into account.

Additionally, in the framework of a hierarchical decision making process hypothesis, multinomial, nested and cross-nested logit models were developed. A sensitivity analysis was then carried out, as well as an elasticity analysis of the crossing location choice to the statistically significant model parameters.

Overall, crossing probability is increased at the beginning of the trip, whereas a tendency of pedestrians to postpone road crossing is identified for longer trips and for pedestrians with increased walking speed. Moreover, crossing probability is increased at signalised junctions, whereas crossing at mid-block is more likely to occur on one-way road and in low traffic volumes. From the comparative assessment of the various models developed, it can be deduced that a **sequential decision making process hypothesis** is more generic, given that the dynamics of the decision making process are taken into account, whereas the choice analysis is not conditional to the availability of the alternatives. Moreover, the parameter estimates are easier to interpret and models fit is more satisfactory as well.

The proposed methodology and the analysis results are demonstrated within an **application of the models** for a typical trip in the centre of Athens, for four scenarios including different traffic conditions and different types of pedestrians. The shape of the distribution of pedestrians' risk exposure along this trip is similar in all scenarios and only the magnitude of risk exposure changes from changes in the examined parameters. From this distribution, specific locations with increased pedestrian risk exposure are identified within the trip. Pedestrians risk exposure increased with traffic volume and decreases with pedestrian speed. It is also observed that pedestrians with increased walking speed may partly compensate for their risk exposure, so that it is not significantly affected by traffic volume.

From the results of the analysis, a **group of critical variables** is identified (traffic volume, number of lanes, traffic signals and pedestrian's speed), which are common in both the description of pedestrians' behaviour and the estimation of their risk exposure. Pedestrians risk exposure is strongly associated with both the behaviour of pedestrians and the characteristics of the road network and the trip, and that type of analysis of pedestrians' risk could not have been achieved if a typical macroscopic approach had been implemented.

Moreover, a notion of **variable risk exposure of each location of the road network** is outlined. More specifically, 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. Consequently, for the accurate estimation of the risk exposure corresponding to a location of the road network, it is necessary to estimate the crossing probability at this location for all the pedestrian trips including this location.

The proposed methodology and results can be exploited in **future research** aiming to develop and implement related approaches for the analysis of pedestrians' behaviour and safety in urban areas. In particular, further research in the field may contribute to the description of the crossing behaviour of pedestrians and their response to road infrastructure of traffic management interventions. Moreover, it may contribute towards a more accurate estimation of pedestrians' risk exposure, as regards both the detection of locations with increased risk exposure for pedestrians, and the elaboration of measures for the improvement of pedestrians' safety.