Generation of road accident risk maps

A. Ilharco[1], A. Bastos[2], J-P Elvas[3], A. de Almeida[4]

[1] Department of Informatics Engineering, University of Coimbra

AmIlab - Ambient Intelligence Lab at Coimbra

ana.ilharco@gmail.com

[2] Department of Civil Engineering, University of Coimbra

..., abastos@dec.uc.pt

[3] Department of Mathematics - Lab.of Geomatic Engineering, University of Coimbra

INESCC - Institute for Systems Engineering & Computers at Coimbra

zepaulo@mat.uc.pt

[4] Department of Mathematics - ISCTE - University Institute of Lisbon

CISUC at Coimbra

amaria@dei.uc.pt

Abstract

Knowing the factors that affect the likelihood of an accident occurrence has been increasingly challenging to the researchers given the huge social and financial costs that derive from road accidents.

In Portugal, developments in this area have mainly involved interurban roads studies. However, according to ANSR[i], about 70% of Portuguese road accidents occur in urban spaces, a trend common to most European countries. The lack of national or local information systems containing geo-referenced road accidents, geometric characteristics of roads, among others, hamper the creation of tools that help to assess the risk of exposure at a micro level, *i.e.* road intersections.

The weaknesses mentioned above led us towards the implementation of models in a GIS-based environment in order to estimate the frequency of accidents for urban areas according to several breakdowns: road element, type of accident and the inclusion of explanatory variables related to road environment. One of the challenges faced by researchers when applying these models is the absence of data or its poor quality. Therefore, it is necessary to cross and analyse information from different sources, such as traffic variables (from model transportation planning), digital cartographic data, and other geometric variables, that may not be obtained in a direct way (*e.g.* using OpenStreetMap or Google Maps). In a further step, the estimation models will be programmed and applied according to the type of road element (*e.g.* intersections, roundabouts, segments).

Finally, new information will be generated with all inputted data: a digital map with the number of accidents per road element. Such figures will need to be converted into something more meaningful for potential users, such as levels/categories (*e.g.* high, medium and low risk of exposure), which can be mapped.

This paper proposes a methodology for automatic generation of road accident maps with those levels/categories. Thus, maps will serve as a decision support tool not only to insurers (who are likely to tax drivers more effectively, according to their exposure to risk), but also to drivers themselves (through generation of alarms that will allow them to tailor their driving performance), envisaging road safety improvement.

Keywords: road accidents; risk maps; CPM; urban; GIS.

1 Introduction

The Sustainable Urban Mobility Plans (SUMP) define a set of interrelated measures designed to meet the needs of individuals and business mobility now and in the future. They are the result of an integrated planning approach that encompasses all forms of transportation in cities and their surroundings.

Around the world in general and Europe in particular, there are a number of promising innovative concepts for the development of sustainable mobility schemes (at local or regional level). These concepts range from projects to promote pedestrian and cycling travelling to new forms of use and possession of vehicles, encompassing a broader term that is called "soft" mobility management. The goal of all these concepts is to achieve a significant reduction in CO_2 emissions from personal transports or a change in modal split to forms of sustainable transportation (European Comission, 2012).

The need for more sustainable and integrating planning processes, especially in what concerns urban related sectors, has been growing recognition. In Europe, they have been deserving special attention, has shown by some directives and policies present in some special documents written by the European Comission (Europeia, 2007, 2011). SUMP is a new or practically inexistent reality in other parts of EU, while United Kindgom and France are the only ones actively pursuing this matter (Bührmann, Wefering, and Rupprecht, 2011).

In this context, **TICE.MOBILIDADE**[ii] was born in Portugal — a project that aims to provide a digital platform for mobility services focused on the user, combining mobility, energy optimization and management of urban spaces. TICE.MOBILIDADE pursues the development of a marketing platform mobility services designated "One.Stop.Transport" (OST) and the development of various products, processes or systems (PPS), which will be marketed on the platform, but with autonomous strategies.

The work here presented is part of one of those PPS called "**2STAX** - Systems and Services Tax", which domain problem is related to car insurance.

Costs related with high claim ratios are a daily problem faced by insurers and their clients. There are little or no proactive actions on claim prevention or promotion of client consciousness, which result in high claim ratios. These costs are even higher if we consider that some of these claims are fraudulent.

On one hand, insurers are penalised with the high costs resulting from the claims and, on the other hand, final clients pay more for a product which involves high administrations costs and inefficient risk exposure evaluation.

With the use of telematics technologies in the insurance business, 2STax will allow to sell products more dynamically, tailored to fit client needs (PAYD — Pay-As-You-Drive), in particular concerning risk exposure. This “customised” service may lead to customer loyalty and higher sustained economic growth.

Very briefly, 2STax solution includes the developing of services which enable:

1) Generation of road accidents risk maps;
2) Smart insurance rating depending on vehicle usage (total distance, roads used, circulation times, etc.);
3) Automatic generation of driving profiles (the relationship between road sections and usage profile is an innovation that will be useful to road safety authorities);
4) Real-time notification of drivers when approaching an area of greater risk (considering accident history information);
5) Interactions with the emergency and roadside assistance services based on context and vehicle location;
6) Improvement of procedures associated with an accident, taking advantage of data stored on the time period preceding the accident.

This paper relates only to number 1), i.e. systematizing a methodology to generate road accident risk maps. This automatization will be implemented in a Geographical Information System (GIS).
This way, it can be foreseen as the most significant contributions of this work the follows:

- Offer maps, especially tailored to car insurers, non-existent maps in the Portuguese market to this date.
- More precise and dynamic rating procedures by analysing the risk associated with a given place at a given moment.
- Decrease of road accidents by creating more awareness among customers through notifications warning about the risk associated with a particular road segment.

2 Methodology

Initially, this project was expected to include the acquisition of real road accidents history (not only the ones with injuries/deaths, but also those with property damage only) and, based on that data, directly classify areas according to the risk observed over the years. That is, density maps with georeferenced accidents (by district, county, parish, or any other region properly delimited) could be developed using, for instance, simple density and Kernel methods in order to identify areas most prone to road accidents (called *hotspots*) as proposed in (Jayan & B., 2010).
However, this methodology was discarded due to several factors:

- Difficulties in data providing, because they are scattered by various entities and it is a lengthy and demanding process under the bureaucratic point of view (usually requires signing protocols to request and obtain data).
- Lack of accuracy: due to missing or inaccurate georeferencing (e.g. only street name appears, some names are misspelled).
- Incomplete databases of road accidents (accidents with property damage only are not required to participate to the authorities , so even the most complete national database, which belongs to National Authority for Road Security (in portuguese, ANSR), only registers accidents with injuries).

As an alternative, it was decided to estimate the accidents based on conventional estimation models.

This way, the new methodology, as illustrated in Figure 1, begins with the selection of estimation models, then the survey of explanatory variables (according different sources) for each type of road element (intersection, segments and roundabouts) in those models, through the GIS environment where all the data is collected and treated, ending in the generation of new information: a map with the number of accidents *per* road element. This output should be subject, if possible, to a sensitivity analysis, using for that purpose the ANSR's aggregated data.

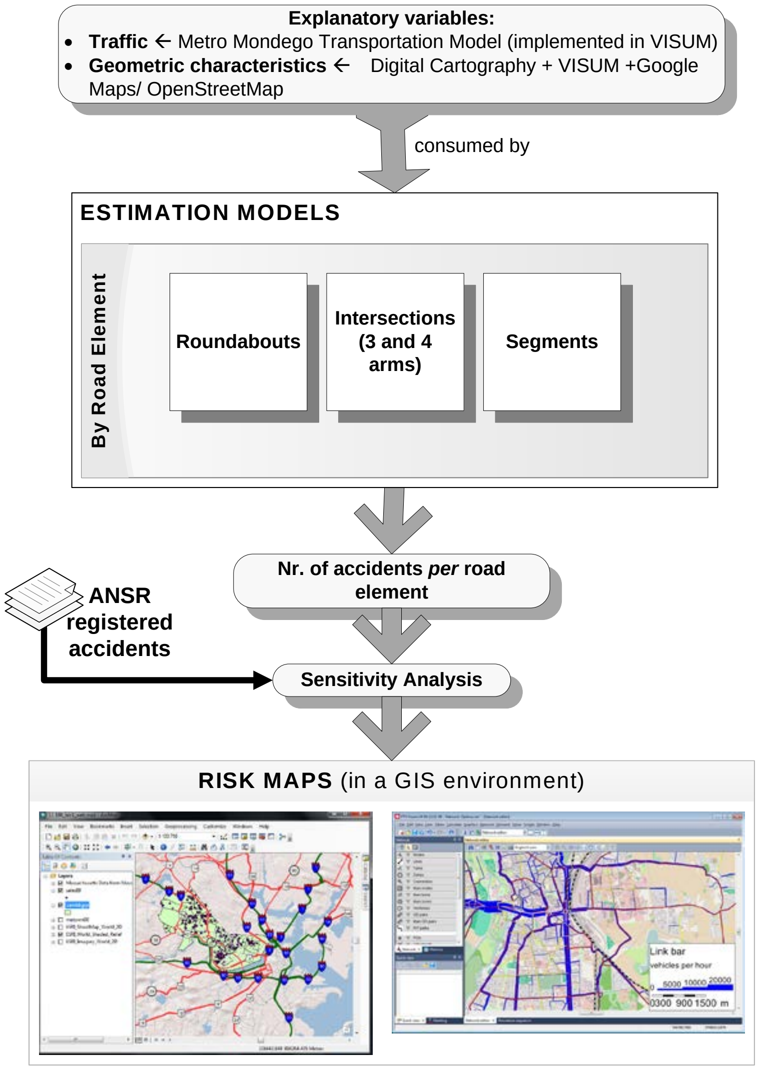

Figure 1. Simple scheme of the adopted methodology to generate risk maps using GIS.

2.1 Model selection

As stated earlier, this work will apply estimation models that will be mentioned as **CPMs** (Collision Prediction Models) from now on. Following the consulted literature (Cardoso, 1996; Gomes, 2010), it is important to distinguish CPMs as to:

1) The classification according to the level of disaggregation of the response variables used.
2) The functional form of the mathematical equations (models).

Regarding point 1), there are two types of models: the aggregated and the disaggregated (from now on referred to as **macro** and **micro** models, respectively). The macro models describe general trends in road accidents at national, regional or zone level (also known as Traffic Analysis Zone ,TAZ, which is the unit of geography most commonly used in conventional transportation planning models. A Zone generally consists of one or more census blocks, usually depending on traffic, macroeconomic and demographic variables, land use, among others.
In turn, the micro models allow to represent changes that may occur in specific parts of the transportation system or in the safety of certain user groups. The most commonly used types of disaggregation are by age group, gender, mode of transportation and type of road element (e.g. segments, intersections, roundabouts).
As for point 2), the functional form of the mathematical equations is usually obtained through regression analysis, in which is possible to distinguish two types: simple regression and multiple regression models. A Simple Linear Regression Model (SLRM) describes the relationship between a quantitative variable X and a quantitative variable Y, while a Multiple Regression Model (MRM) describes a relationship between a set of quantitative explanatory variables $X_j(j = 1,2, \dots, J)$ and a quantitative response variable *y*, by the expression:

$$y_n = \alpha + \beta_1.\left(X_{1n} - \overline{X_1}\right) + \cdots + \beta_j.\left(X_{jn} - \overline{X_j}\right) + E_n$$

in which:

- y_n - response variable;
- n - index of the observations of variables $X_1, \dots, X_j$ and $Y(n = 1, \dots, N)$;
- $(X_{1n}, \dots, X_{jn,} Y_n)$ - *n*-th observation of the variables X_1, X_j and Y;
- $\overline{X}_j$ - arithmetic mean of the observations of the variable X_j ($\overline{X}_j = \frac{1}{N}.\sum_n X_{jn}$)
- $\alpha, \beta_1, \dots, \beta_j$ - fixed parameters to estimate from the linear relationship between X_1, X_j and Y;
- E_n - random error associated with the observed value Y_n.

Generalized Linear Models (GLMs) represent an extension of multiple regression models by allowing the response variables to have other than a normal distribution (e.g. other distributions that belong to exponential family such as Poisson, Binomial, Gamma, Inverse Gaussian).
To choose the distribution of the response variable it is necessary to carefully examine the data; for instance, Normal and Gama distributions are suitable for modelling data with a continuous nature and showing asymmetries, while generalized Poisson models (or log-linear models) are often referred to as models for data count, such as the number of road accidents. The generalized model of Negative Binomial (NB) (or Poisson-gamma) can be considered a variation of the previous model, allowing cater for the effects of the overdispersion (variance higher than the average) in data analysis. In fact, several studies (Abdel-Aty and Radwan, 2000; J.Maher and Summersgill,

1996; Lovegrove and Litman, 2008) have shown the inadequacy of the conventional linear regression for modelling rare events, discrete and non-negative, such as accidents occurred on a road element. So it is not surprising that the vast majority of those studies on accidents estimation follows a GLM with Poisson or NB distributions (or variations of both).

Applied models in Portugal

CPMs' investigations published and applied in Portugal are still very few. We have identified, at least, three of those scientific studies (Cardoso, 1996; Ferreira, 2010; Gomes, 2010) and considered Sandra Gomes' PhD thesis (Gomes, 2010) as the most relevant and suitable in terms of accident modelling for urban spaces, which is the aim of the present work.

Her work comprised two important parts:

- The first one: creation of a database with geo-referenced accident data occurred in Lisbon city between 2004 and 2007. This database has required crossing several data sources (both in digital and paper form), and it provides a wide range of queries and could be used to validate the results obtained by the estimation models.
- The major one: development of CPMs at a micro level, according many unbundlings, as will be mentioned later in this document, the most relevant being the disagreggation by road element as presented in Figure 1.

From now on, we will work with these models, not only due to the short duration and nature inherent to our work, but also because our goal is to focus on developing a new methodology to generate risk maps in a GIS environment.

The lack of detailed data on driving (acceleration, braking, information on the maneuvers of the steering wheel, the driver's responses to various *stimuli*) or on accidents (which could be available, for instance, through black boxes), led the study of (Gomes, 2010) to approach the problem by reducing it to the understanding of factors that affect the frequency of accidents occurring in a given geographic area (usually a segment or intersection) for a certain period of time (year). As such, the gathering and processing of the data needed to apply these models represents a great and important part of the entire study. So, the developed models require, basically, two things:

a) Vehicular and pedestrian traffic.

b) Characteristics of the road environment.

Regarding point a), traffic is absolutely indispensable in any estimation models of road accidents. The variable in question is called Annual Average Daily Traffic (**AADT**) and can be used to designate both vehicle and pedestrian traffic. The pedestrian traffic data was obtained exclusively by counts, but the number of places subjected to counts had to be limited as a consequence of being an onerous and time consuming process. In its turn, the collection of vehicle AADT was performed for 55 intersections, adding up both light and heavy vehicles' AADT. Such collection was done using either counts (manual or automatic) or estimates from a traffic allocation model of an earlier study of the National Laboratory of Civil Engineering (in portuguese, LNEC - Laboratório Nacional de Engenharia Civil), conducted by Sandra Gomes and João Cardoso in the year 2008.

Point b) involved different sources:

- Detailed cartography of the city, containing the numbers of each building;
- Description and location of the axis of the road network in the county;
- Location and identification of street lamps.
- Survey of geometric characteristic of road elements by LNEC's specialized technicians.

Having already defined the collection of data required by the models, it remains to ascertain how are they classified according to the functional form of the mathematical equations. The models were developed using GLM (applying the maximum likelihood method) with an error component following a NB distribution. As mentioned previously, the overdispersion phenomenon is very common in this type of study and this was no exception.

Model's disaggregation

The study performed by (Gomes, 2010) considered two distinct types of response variables according to the accident's nature: Running Over (RO) and the remaining accidents with victims (NRO). Additionally, other disaggregations were considered:

- by road element: 3-leg and 4-leg intersections, roundabouts and segments;
- according to the inclusion of explanatory variables relating to the road environment:
    - Simplified (S) , if only the traffic variables are included.
    - Global (G), if all the potential explanatory variables are integrated in the equation.

  This duality of functional forms was defined in order to complement the traditional view, which normally relates accidents only to exposure factors (such as traffic).

Figure 2 outlines these disaggregations.

Although the original models contemplate the estimation of accidents by running over (RO), the truth is pedestrian traffic data is nonexistent as well as models developed in that direction, as referred by (Gomes, 2010). Also, there is no possibility to demand these pedestrian traffic counts, so RO estimation models cannot be applied in this work.

With this in mind, Table 1 summarizes the equations of the applicable estimation models.

Table 1. Equations for the estimation models for accidents with victims, excluding running-over. Adapted from (Gomes, 2010).

Road element	Mathematical Equation	Type of Model
3-leg intersection	$\mu_{it} = \beta_0(F_{Tit})^{\beta_1}$	Simplified
	$\mu_{it} = \beta_0(F_{Tit})^{\beta_1} e^{LB_i \times \beta_2 + LWMAJ_i \times \beta_3 + RTPMAJ_i \times \beta_4 + TCD_i \times \beta_5}$	Global
4-leg intersection	$\mu_{it} = \beta_0(FVP_{Tit})^{\beta_1}$	Simplified
	$\mu_{it} = \beta_0(F_{Tit})^{\beta_1} e^{LB_i \times \beta_2 + LMAJT7_i \times \beta_3 + LWMIN_i \times \beta_4 + RTPMIN_i \times \beta_5 + LOW_i \times \beta_6}$	Global
3 & 4-leg intersections (all together)	$\mu_{it} = \beta_0(F_{Tit})^{\beta_1}$	Simplified
	$\mu_{it} = \beta_0(F_{Tit})^{\beta_1} e^{LMAJT7_i \times \beta_2 + LWMAJ_i \times \beta_3 + MMAJ_i \times \beta_4 + RTPMAJ_i \times \beta_5 + LOW_i \times \beta_6}$	Global
Roundabouts	$\mu_{it} = \beta_0(F_{Tit})^{\beta_1}$	Simplified
	$\mu_{it} = \beta_0(F_{Tit})^{\beta_1} e^{LEG_i \times \beta_2}$	Global
Segments	$\mu_{it} = \beta_0(F_{Tit})^{\beta_1} \times L_i^{\beta_2}$	Simplified
	$\mu_{it} = \beta_0(F_{Tit})^{\beta_1} \times L_i^{\beta_2} \times e^{NLANES4_i \times \beta_3}$	Global

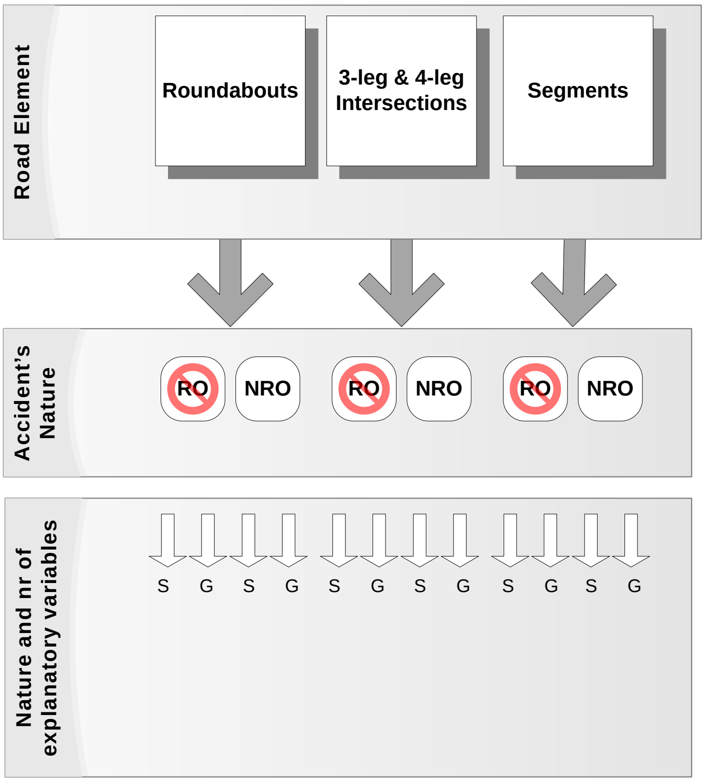

Figure 2. Disaggregations considered by the adopted models. Adapted from (Gomes, 2010).

2.2 Data collection

To apply the previous models it is necessary to compile or measure some data (the most important, AADT, and the prevailing geometric characteristics of each road element).

In Portugal, data on vehicle traffic is very scarce — there are no official databases and this type of count is sometimes, not very often, carried out by local authorities, but only in certain locations and for other purposes. Moreover, most of the time, this data isn't saved due to implicit high storage costs or because it is only necessary for traffic control in real time. Therefore, the remaining alternative was to use the Transportation Model recent developed by Metro Mondego for the city of Coimbra (this model was implemented in PTV VISUM, a GIS-based software more suited for transportation planning, which is the case). The idea of using this model is to take advantage of the vehicle traffic per each network's link (AADT) and, if possible, try to export the urban road network in order to benefit from other road characteristics that might be found in it and reused on our chosen software, ArcGIS.

In turn, the explanatory variables for each road element are not as trivial as calculating the average length of the street — it involves obtaining features such as the average width of the entry road lanes at an intersection's main direction, the number of one-way lanes at an intersection, among others, as can be seen in Table 2.

Table 2. List of the all the explanatory variables required by the selected estimation models.

Variable's description	Variable	Values for binary variables
Incoming traffic in vehicles per day (AADT) at the intersection *i* in year *t*	F_{Tit}	N.A.
Traffic, in vehicles per day (AADT), in both circulation directions of the segment *i*	FVP_{Tit}	N.A.
Balance of lanes at intersection *i*	LB_i	0 - no 1 - yes
Number of legs (road segments) of intersection/roundabout *i*	LEG_i	0 - 3 legs 1 - 4 legs
Number of lanes in the main direction of an intersection *i* =3 or more	$LMAJT7_i$	0 - no 1 - yes
Number of one-way lanes at intersection *i*	LOW_i	N.A.
Average width of the entry road lanes at the main direction of an intersection *i* (m)	$LWMAJ_i$	N.A.
Average width of the entry road lanes at the secondary direction of an intersection *i* (m)	$LWMIN_i$	N.A.
Total length of segment *i* (m)	L_i	N.A.
Presence of a central divider between of one of the legs in the main direction of intersection *i*	$MMAJ_i$	0 - no 1 - yes
Number of lanes is equal or greater than 4 for segment *i*	$NLANES4_i$	0 - no 1 - yes
Presence of exclusive right-turn lanes in the main direction of an intersection *i*	$RTPMAJ_i$	0 - no 1 - yes
Presence of exclusive right-turn lanes in the secondary direction of an intersection *i*	$RTPMIN_i$	0 - no 1 - yes
Presence of traffic control system at intersection *i*	TCD_i	0 - no 1 - yes

Estimated number of accidents at intersection *i* in year *t*	μ_{it}	N.A.

2.3 GIS approach

Figure 3 illustrates the GIS approach carried out in this work. This approach implies centralizing all the data about the network infrastructure and the explanatory variables from different sources (and make some pre-processing, if needed) in a GIS software (ArcGIS, on our case).

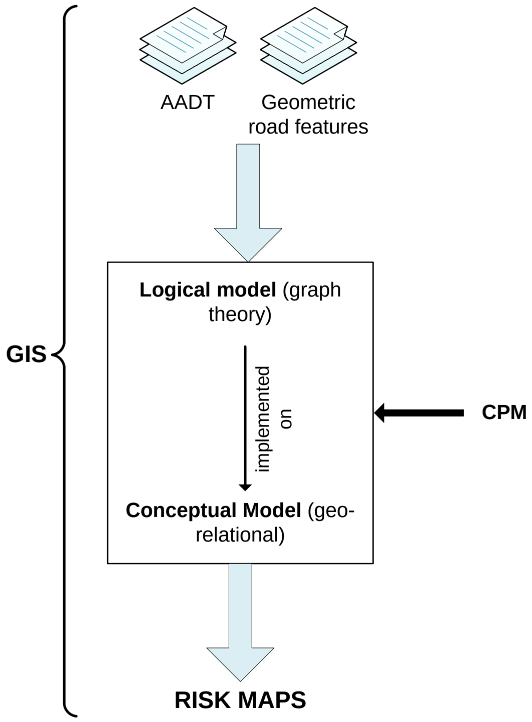

Figure 3. GIS scheme to be implemented.

The software relies on a logical model in which each geographical primitive (arc or node), corresponding to a particular geographical/road element, has an associated relational table with certain attributes: standard and others than can be defined user-defined (see Figure 4).

Then it is possible to implement the formal models chosen (CPMs) by programming, if the built-in tools don't allow to do that association more directly. In the end, after applying the models , GIS generates new information and allows previewing it in the form of maps and manipulating them as desirable. In the present case, the map with the number of accidents *per* road elements, i.e. the output, should be translated to something more visual meaningful, for instance, a map with levels of exposure to risk (e.g. high, medium and low risk exposure categories would correspond to red, yellow and green colours, respectively).

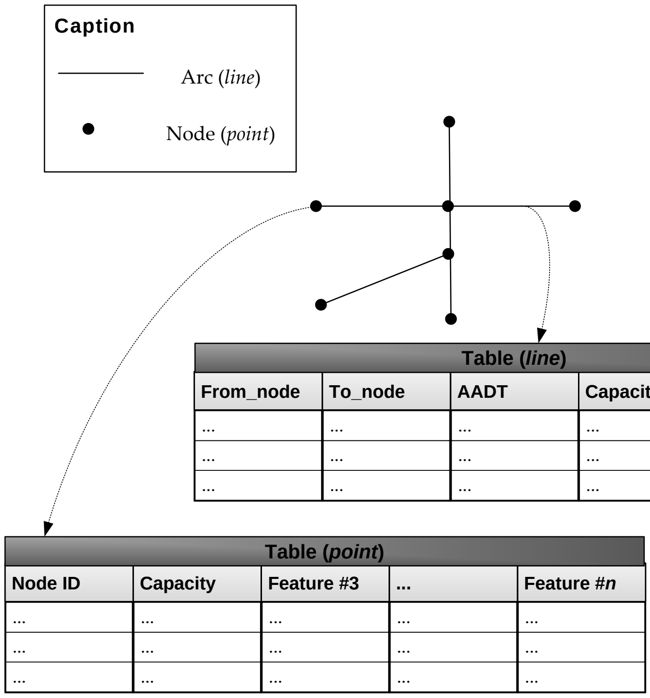

Figure 4. Logical model of a GIS software.

3 Conclusions and future work

The evaluation of the risk of exposure associated with a road element (or geographical entity) represents a serious gap in the car insurance companies. On one hand, the insurers are not provided with decision support tools to enable them to identify which areas are most prone to accidents. On the other hand, there are no proactive measures in order to warn the drivers of the risk of accidents. Leveraging this flaw, the project TICE.Mobilidade has created a PPS called *2STax* that fits the philosophy "Pay as You Drive" , which can be resumed in providing means for smart charging automobile insurance. This work, called GMR (in portuguese, Geração de Mapas de Risco), is part of that PPS and is responsible for systematizing a methodology for automatic generation of risk maps that can assist insurers.

Given the difficulties in obtaining data on road accidents, the direct classification of areas according to the risk observed over the years (e.g. defining *hotspots*) became unworkable. Therefore, it was necessary to rethink a new methodology, including using models to estimate accidents. The models chosen to be applied have been previously implemented in the city of Lisbon and are disaggregated by road elements such as intersections, roundabouts and segments.

Being micro models turned out to be ideal:

— because the smart insurance charging will be more accurate and fairer, the more detailed and micro the models are. Evaluating the risk road element by road element is more specific and thorough than having an idea of risk exposure looking at some areas/zones on a map.

- since it was found that the level of risk is more related to a combination of factors related to the infrastructure rather than with anomalous values of a single factor (such as land use, environmental factors and transversal data - none of these data is available for us).

However, applying these models also offers some limitations, due to the lack of data on pedestrian traffic and the fact that the gathering of some explanatory variables is not so direct as it was believed. Consequently, we will only be able to apply CPMs for non running-over accidents (NRO), i.e., remaining road accidents with victims. The idea is to try our methodology on a single area/zone of Coimbra and then, if possible, expand to other areas or even other Portuguese cities.
Therefore, the interest of this work is unquestionable, and may be useful not only in the area of car insurance, but also in safety, transportation planning and management areas.

As future work, it would be interesting to develop new and more robust models even more suitable to our needs. We are aware that the creation of estimation models requires considerable effort in the calibration and validation phases, in order to not undermine the credibility of the results. For this reason, we decided not to "reinvent the wheel" and create something that would probably take much time and even resources that we do not own in the present. Moreover, the existence of models for pedestrian traffic counts would help to overcome problems that arise from the needs and costs associated with those counts. With these improvements, we would be able to apply CPMs for running-over accidents (RO) in the same way we do with other accidents and achieve a more complete decision tool.

References

Abdel-Aty, M. A., & Radwan, A. E. (2000). Modeling traffic accident occurrence and involvement. *Accident Analysis and Prevention*, *32*(5), 633–42. Retrieved from http://www.ncbi.nlm.nih.gov/pubmed/10908135

Bührmann, S., Wefering, F., & Rupprecht, S. (2011). *Guia Desenvolvimento e implementação de um plano de mobilidade urbana* (Vol. 2.2). Retrieved from http://mobilityplans.eu/docs/file/SUMP_Guidelines_final_PT_web.pdf

Cardoso, J. P. L. (1996). *Estudo das relações entre as características da estrada, a velocidade e os acidentes rodoviários. Aplicação a estradas de duas vias e dois sentidos em zonas não urbanas*. Universidade Técnica de Lisboa.

European Comission. (2012). EU initiatives and policies. Retrieved January 15, 2013, from http://www.mobilityweek.eu/resources/useful-links/eu-initiatives-projects/

Europeia, C. (2007). Livro Verde: Por uma nova cultura de mobilidade urbana. *Livro Verde*, (COM(2007) 551 final), 25. Retrieved from http://eur-lex.europa.eu/LexUriServ/LexUriServ.do?uri=COM:2007:0551:FIN:PT:PDF

Europeia, C. (2011). Livro Branco: Roteiro do espaço único europeu dos transportes : rumo a um sistema de transportes competitivo e económico em recursos. *Livro Branco dos Transportes*, (COM(2011) 0144 final), 15. Retrieved from http://eur-lex.europa.eu/LexUriServ/LexUriServ.do?uri=COM:2011:0144:FIN:PT:PDF

Ferreira, S. M. P. (2010). *A Segurança Rodoviária no Processo de Planeamento de Redes de Transporte em Meio Urbano*. Universidade do Porto.

Gomes, S. C. G. V. (2010, April). *Avaliação da influência da infra-estrutura na segurança rodoviária em meio urbano*. Universidade de Coimbra, Coimbra. Retrieved from http://hdl.handle.net/10316/14578

J.Maher, M., & Summersgill, I. (1996). A comprehensive methodology fitting of predictive accident. *Accident Analysis and Prevention*, *28*(3), 281–296.

Jayan, K. D., & B., G. (2010). Identification of Accident Hot Spots: A GIS Based Implementation for Kannur District, Kerala. *International Journal of Geomatics and Geosciences*, *1*(1), 51–59. Retrieved from http://www.indianjournals.com/ijor.aspx?target=ijor:ijggs&volume=1&issue=1&article=005

Lovegrove, G. R., & Litman, T. A. (2008). Using Macro-Level Collision Prediction Models to evaluate the road safety effects of mobility management strategies: new empirical tools to promote sustainable development. Transportation Research Board. Retrieved from http://citeseerx.ist.psu.edu/viewdoc/download?doi=10.1.1.186.4693&rep=rep1&type=pdf

Acknowledgements

This work was supported by FEDER founds through the Portuguese Sistema de Incentivos à Investigação e Desenvolvimento Tecnológico in the scope of the project TICE.Mobilidade, operative program Fatores de Competitividade (FCOMP-01-0202-FEDER-013843).

The authors thank PTV[iii] for the provided scientific licence for their GIS software: VISUM v12.5 and an additional module called VISUM Safety Module v12.5.

[i] ANSR - Autoridade Nacional Segurança Rodoviária (National Authority for Road Security) (http://www.ansr.pt/).

[ii] TICE.MOBILIDADE website: http://tice.mobilidade.ipn.pt/index.php

[iii] PTV group's website: http://vision-traffic.ptvgroup.com/en-uk/