PLANNING ON SAFER URBAN MOBILITY THROUGH SPATIAL ANALYSIS: APPLICATION TO VILA REAL, PORTUGAL

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Abstract

Land use and transportation interactions have been subject to different studies. Analytical studies on synergies between road safety and the road environment is also very relevant yet less common. It has long been known that urban road accidents tend to cluster in particular sites and that this often indicates an inadequacy between the urban road environment and its current functions (Levine *et al*., 1995; Elsenaar and Abouraad, 2005; Elvik, 2006). Improving the road environment where accidents road users' behaviour to prevailing circumstances. Designing self-explaining roads (Theeuwes and Godthelp, 1995) can contribute to increasing road safety for drivers and vulnerable users (e.g. pedestrian and children) whilst improving cities general environment.

An efficient approach to reduce the number and severity of urban road accidents is the identification, analysis and treatment of road sites where road accidents tend to aggregate, i.e., hazardous road locations (HRL) (CIHT, 1990). However, no commonly accepted definition for HRL has been established. Moreover, many countries – like Portugal – do not systematically apply HRL programmes and, indeed, have insufficient resources allocated to road safety.

The aim of this research project described was to compare and discuss the applicability of different existing HRL definitions as well as their respective identification methods given the current availability of road accident and exposure data and resources in Portuguese local authorities.

Within this context, three types of HRL identification methods were applied. Analyses were carried out using two spatial analysis software packages for road accident data from the Portuguese city of Vila Real. Application of the different methods and their respective parameterisation led to the identification of different numbers and locations for HRL; however, a considerable number of HRL was regularly identified using distinct methods and/or parameter values.

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The adequacy and effectiveness of the diverse methods is analysed. Results indicate the suitability of the applied methods and their potential as tool leading to the identification of measures to improve road safety in countries with limited availability of resources available to significant urban environmental changes. The study here described also suggests that the integration of HRL identification and treatment with the general transport and land use policies will be beneficial by promoting best use of resources.

1. Introduction

Urban road accidents are responsible for considerable human and material losses all over the world, of which a large proportion occur in urban environments (ECMT, 2006; WHO, 2011). The need to seriously address this situation led the UN to launch the Decade of Action for Road Safety in 2011.

An efficient approach to reduce the number and severity of road accidents as well as their casualties, in particular in urban areas, is the treatment of locations(s) where these tend to aggregate, the HRL (CIHT, 1990). Despite its effectiveness, this approach has not been systematically implemented in many countries, including Portugal. As there is no commonly accepted international definition for HRL (Geurts and Wets, 2003; Geurts, *et al*., 2005; Cheng and Washington, 2008; Anderson, 2009), this work intends to compare and discuss the implementation of methods and definitions that enable its identification in countries within this context. A case study has been developed in the Portuguese city of Vila Real and took into account the current road accidents and exposure data availability and quality and scarce resources allocated to road safety by Portuguese local authorities. Dealing with HRL entails their identification followed by ranking, detailed analyses (see section 2.2) and identification and implementation of corrective road safety measures. This study focuses on the first stage.

To apply such approach spatial data analysis software, such as Geographic Information Systems, are commonly applied. Those spatial tools are also used for many purposes, including helping urban planners to identify, analyse and promote corrective interventions to solve urban problems. As urban characteristics have influence on road safety, planning and road safety approaches should be combined in order to seek solutions taking into consideration a wider perspective of the complex urban problems.

2. Hazardous Road Locations

2.1 Identification

Road accidents often accumulate in particular sites, the hazardous road locations. The investigation of factors which lead to accidents' clusters is an important topic in the road safety activity (Moons *et al*., 2009), since it is a strong indicator of a road related problem (Elsenaar and Abouraad (2005).

Several different methods have been applied to identify these locations (Retting, *et al*. 2001; Hauer, *et al*. 2002; Flahaut, *et al*. 2003; Brijs, *et al*. 2007; Elvik 2008; El-Basyouny and Sayed 2009; Pirdavani, *et al*. 2010).

Elvik (2007), based on an OECD report, proposed a distinction between the different definitions of HRL into:

- *Numerical*: locations where usually the recorded accident number or rate (e.g. accidents per traffic flow), during a period, is higher than a threshold;
- *Statistical*: locations where the recorded accident number or rate is significantly higher than the usual, taking into account the type of location (e.g. an intersection). Examples of this type definition can be found in Elvik (2008) and Erdogan *et al*. (2008);
- *Model-based*: locations identified based on the recorded and expected accident number taking into account the characteristics of the place. The expected number of accidents is obtained through an accident prediction model. There are several of these models (Lord and Mannering, 2010).

Generally, the identification through *numerical definitions* can be applied with information only about the road network and accidents, including their location. These definitions identify sites where the recorded number of accidents (or their rate if an exposure measure, such as traffic flow, is also available) during a period, is higher than a threshold. Examples are presented in Table 1. The remaining types of definitions require complementing information, such as traffic data, which is often not available, especially in countries where road safety programmes have not been recurrently applied (Sørensen, 2007). For this reason, *statistical* and *model-based* definitions were out of the scope of this work.

Table 1. Some of the operational numerical HRL definitions found in literature

Definition	ANSR	Belgium	Flanders	Hungary	Germany	Norway
Period of records	1 year	Over 1 year	3 years	3 years	3 years	5 years
Location (road extension)	100 m	50 m	50 m	50 m	50 m	50 m
Severity index (SI)	SI=100F+ +10SerI+ +3SliI	-	SI=5F+ +3SerI+ +SliI	-	-	-
Criterion 1: No. of accidents	≥ 5	≥ 3 serious	≥ 3	≥ 4	≥ 5 with casualties or ≥ 3 serious	≥ 4
Criterion 2: Severity index	∑ SI > 20	-	∑ SI ≥ 15	-	-	-

Definition	ANSR	Belgium	Flanders	Hungary	Germany	Norway
Source	ANSR, 2011	Flahaut *et al.*, 2003	Elvik, 2007; Geurts *et. al.*, 2006	Elvik, 2007	Elvik, 2007; 2008	Elvik, 2007; 2008

Legend: F – fatal injury; SerI – seriously injured; SliI – Slightly injured

Besides the abovementioned definitions, other practical methods were applied in this study with the purpose of identifying HRL (Retting *et al*. 2001; Mungnimit *et al*.,2009; Xie and Yan, 2008). Examples are the *Kernel Density Estimation* and the nearest-neighbour methods (Anderson, 2009; Nicholson, 1998).

To apply these definitions and/or methods, the use of spatial analysis software has been suggested (Elsenaar and Abouraad, 2005). Specialised literature lists a range of available options (TRL, 2011; TES, 2011; Jarvis and Kamal, 2009; BioMedware, 2010, Levine, 2010), including the two (ArcGIS™ and CrimeStat®) adopted in this study (see section 4.2).

2.2 Subsequent steps of a HRL programme: HRL ranking detailed analysis

After the identification of HRL, these sites are usually ranked in order to select a few priority sites for further detailed analysis. Possible ranking criteria are accident frequency, accident rate, proportion of accident types considered susceptible for treatment and severity of casualties. The selection, often made by local authorities, includes political, economical or logistical aspects. Selected sites are particularly analysed in order to understand what may be the causes of road accidents, and which might be suitable for treatment. These analyses often include site visits or production and analysis of stick diagrams which identify common patterns among accidents that occurred in the same place, contributing to the elaboration of countermeasures. There are cases that a special focus is given to particular type of road users (e.g., children, elderly, vulnerable road users) or a specific road accident type. It is, however, important to state that accident analysis may not lead to the finding of common contributory factors to road accidents in a HRL, as they might be an outcome of random circumstances.

3. Methodology

The proposed innovative methodology aims at comparing HRL identification procedures, which can be adopted with limited resources and information, usually available in Portuguese local authorities. Each tested approach is required to be applicable to any urban area using basic generically available accident and road data and common software (GIS or other programs with analytical capabilities for spatial data). This work comprises: (1) data collection; (2) implementation of different methods to identify HRL; (3) discussion of the results, and (4) detailed analysis of the accidents that occurred in selected HRL.

3.1 Data collection

The first step of the methodology is the delimitation of the urban area under analysis. For this area indispensable datasets are identified, and after a formal request have been accepted, road accident data and road network information is collected, homogenised and (when needed) georeferenced. If complementary data is available (such as road traffic data and geographic data) it can be integrated in the analysis stage. Road network should be analysed in order to establish the city functional road hierarchy, as it might have an important role in the problem diagnosis and in the recommendation of solutions related with the enhancement of road safety. Usually, this procedure is defined based on the traffic and pedestrian information as well as experts' knowledge, and must be independent of the accident historical information.

3.2 Identification of HRL

In the proposed methodology, the identification of HRL consists in the implementation of three types of methods: (i) methods based on definitions applied in some European countries; (ii) methods based on the Euclidean distance between points; (iii) methods based on the point density.

Methods based on definitions applied in some European countries

These methods have the purpose to reproduce *numerical definitions* (see section 2.1) applied in some European countries to identify hazardous road locations. Chosen definitions were those from: Belgium, Flanders, Germany, Hungary, Norway and Portugal (ANSR), as these are not based on traffic flows (as they might not be available in some countries – see section 2.1), consider the universe of injury road accidents and provide a noteworthy differentiation between them (see Table 1). To replicate these definitions, two methods were created, here named I and II.

On Method I the number of recorded injury road accident data in each definition is previously selected; for each road accident a severity index (SI) is calculated (according to the definition); a radius is fixed, corresponding to half of the road section length present in the definition; the centre of the circle is applied to the entire urban area according to the cells of a grid, with a specific spatial resolution. Then, two calculations are executed: (i) the number of accidents in each circle and (ii) the sum of the severity index in each circle, resulting in two grids. These are then aggregated and a reclassification is made according to the criteria of the definition in practice to identify the HRL.

On Method II the number of recorded injury road accident data in each definition is previously selected; for each road accident a severity index (SI) is calculated according to the definition; along the segments of the road network, regularly distanced points are set; a fixed radius, corresponding to half of the section length of road present in the definition, is considered; a circle with this radius is centred over the regularly distanced road network points; in each circle road accidents are counted and the values of the severity index are summarised; finally, areas within the circles which verify the correspondent criteria of minimum number of road accidents and sum of the severity index given by the definition in use are selected as being HRL.

The definitions which use the definition of *serious* road accident were applied according to the definition adopted by ANSR (2011). Relatively to the Belgian definition, two periods of records were considered: one and five years as that corresponds to the smallest period allowed by this definition and the larger period, taking into consideration the available dataset.

Methods based on the Euclidean distance between points

This type of methods encompasses those that only require the Euclidean distance between points (road accidents) to identify locations where points are spatially aggregated. Examples are:

- *Count coincident points*: when there are more than a specified number of coincident (road accident) points, such location is considered as a HRL;
- *Count points within a neighbourhood of each point***:** (road accident) points within a neighbourhood area of a road accident location (point) are counted; areas where the number exceeds a threshold are selected as HRL; the procedure is repeated for all road accident locations.
- *Identify spatially close point groups*: the Euclidean distance between points (road accidents) is compared to a threshold distance; pairs of points closer than this distance are aggregated and define a spatial cluster); point aggregations are then selected according to an established minimum number of elements. This value does not interfere with the shape or size of point aggregations which are dependent on the value of the threshold distance. The threshold distance can be either defined by the analyst or based on a random distribution of points for which the area and number of points are equal to the case study.

Methods based in density functions

These methods are based on a point density function calculated for all the cells of a grid (after setting a spatial resolution value) covering the entire area under analysis. Cells exceeding a cut-off point density value are identified as HRL. This value is chosen by the analyst and can be adopted according to the size of the identified HRL (e.g., it can be determined according with the maximum distance between the HRL boundary from a road network centreline).

To represent this type of methods, the *Kernel density estimation* (KDE) was adopted. Its application requires these steps: (i) definition of the extension (area of study) and spatial resolution of the grid; (ii) selection of a density function (e.g.: based on the Normal distribution) and a bandwidth value; (iii) application of a symmetrical surface (defined by the selected density function) centred on each injury road accident location point and dependent on the bandwidth value; (iv) calculation, for each grid cell, of the sum of the abovementioned density surfaces' value producing a single surface (kernel density surface) covering the area under study. After this calculation the cells with density over a cut-off value are selected as being HRL.

3.3 Choice of hazardous road location for detailed analysis

After the identification of HRL, these are ranked to prioritise locations for detailed analysis and subsequent identification and implementation of corrective physical schemes. Criteria to rank the identified HRL are: (i) the coincident identification of a particular HRL by different methods; (ii) the number of road accidents that each HRL contained (accident frequency); (iii) the severity of accidents in a particular HRL; (iv) the focus on a particular type of accidents or road user involved in accidents; and (v) the opportunity to collaborate with urban maintenance, improvement or expansion programmes.

3.4 Detailed analysis of a hazardous road location

Within the framework of this study, stick diagrams analyses are carried out. These are analytical tools which present the road accident information in a diagram form supporting the identification of common characteristics between the accidents, including those which can be improved by the implementation of physical alterations of the urban environment (see section Abstract).

4. Application to Vila Real

The methodology presented in the previous section was applied to the City of Vila Real (described below) and led to the identification of several HRL in Vila Real (section 4.2). It also allowed comparison between different definitions and methods currently used in Europe as well as other that have been sporadically used (see sections 2 and 4.2 – Discussion of results).

4.1 Description and data collection

Vila Real, a medium sized city located in the interior north of Portugal, was chosen for the application of this research work. Its hilly urban area has an irregular shape covering 12,8 km^2. It has an organic urban morphology which has evolved from the historical central area in an amphitheatre shape. Technicians of Vila Real local authority identified three functional road levels in its road network. Injury road accident data in Vila Real (2004-2008) were collected from the national database and complemented with information from the local traffic police departments. 381 injury road accidents were georeferenced in the road network.

4.2 Identification of HRL

Methods based on definitions applied in some European countries

Some parameters were adopted in Method I and II, both applied using ArcGIS™ software: Method I was applied using the *Point Density* function to produce a density grid with 10 m-sided cells whereas in Method II equidistant points (distanced of 20 m) were placed along the centrelines of the entire road network.

Firstly, Method I was applied to reproduce the definition of ANSR (Portugal), leading to the identification of 1 to 3 HRL per year (from 2004 to 2008). The same definition when reproduced by Method II led to the identification of 3 HRL (a single HRL in 2004, 2005 and 2007). The comparison between these two results and taking into consideration the computation process of Methods I and II let realising that the latter allows a more accurate reproduction of the definition as explained in the "Discussion of results" section. For his reason, for five definitions only Method II was applied (Table 2). Figure 1 illustrates the results of the Norwegian definition for Method II.

Table 2. Number of identified HRL by Method II for each applied definition

<table>
<tr><th rowspan="2">Years</th><th colspan="13">Definitions</th></tr>
<tr><th>ANSR</th><th colspan="2">Belgium</th><th colspan="3">Flanders</th><th colspan="3">Hungary</th><th colspan="3">Germany</th><th>Norway</th></tr>
<tr><td>2004</td><td>1</td><td>0</td><td rowspan="5">0</td><td rowspan="3">0</td><td colspan="2"></td><td rowspan="3">15</td><td colspan="2"></td><td rowspan="3">8</td><td colspan="2"></td><td rowspan="5">25</td></tr>
<tr><td>2005</td><td>0</td><td>0</td><td rowspan="3">0</td><td></td><td rowspan="3">19</td><td></td><td rowspan="3">8</td><td></td></tr>
<tr><td>2006</td><td>1</td><td>0</td><td rowspan="3">0</td><td rowspan="3">7</td><td rowspan="3">3</td></tr>
<tr><td>2007</td><td>1</td><td>0</td><td></td><td></td><td></td></tr>
<tr><td>2008</td><td>0</td><td>0</td><td colspan="2"></td><td colspan="2"></td><td colspan="2"></td></tr>
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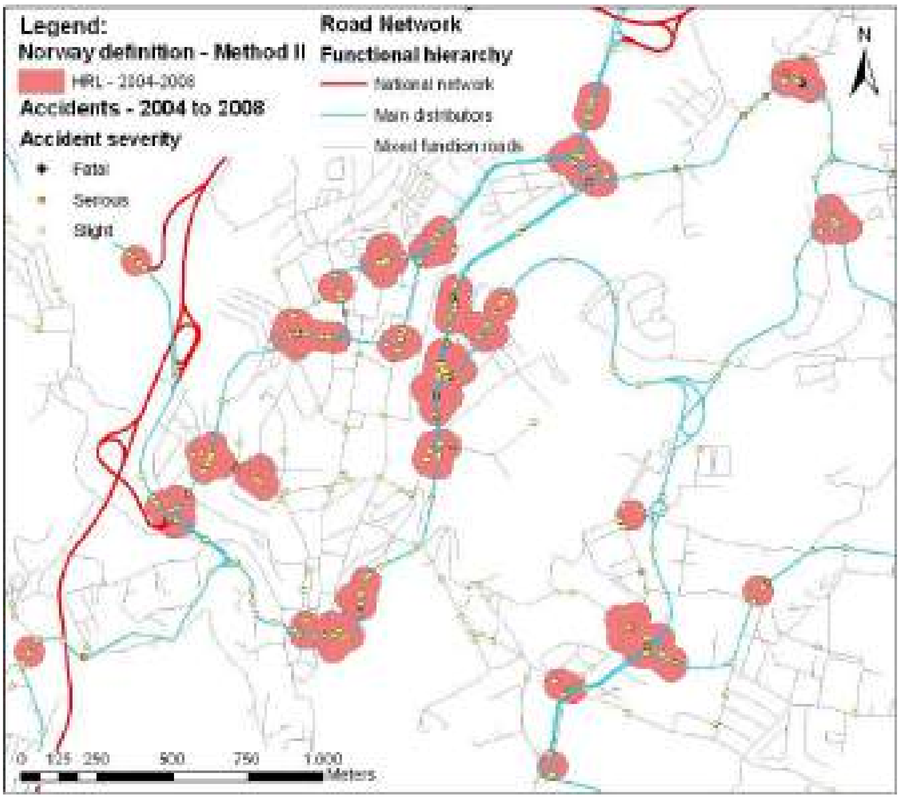

Figure 1. HRL identified with Method II applying the definition of Norway

Methods based on the Euclidean distance between points

The analysis of HRL based on the Euclidian distance between road accident location points was carried out using *CrimeStat®*, a software that includes three routines based on the Euclidean distance between points, usable to identify point agglomerations: (1) *Mode*: counts coincident points; (2) *Fuzzy Mode*: counts points within a neighbourhood of each point, and (3) *Nearest Neighbor Hierarchical Spatial Clustering* (*NNH*): identifies spatially close point groups based on a random distribution of points within the same area and the same number of points as the case study. Its calculation is described in section 3.2. All were applied to the dataset of injury road accidents that occurred between 2004 and 2008 in Vila Real.

In the *Mode* routine only locations with at least three road accidents were considered as hazardous. This criterion was adopted as the occurrence in the exactly same place of three accidents in five years might indicate road safety issues; on the other hand this value, although not isolated, is also used in other definitions (see Table 1). This routine identified one location with four coincident accidents and 4 with three accidents.

In *Fuzzy Mode* routine, a minimum of 4 accidents were adopted as the selection criterion to the HRL identification and two values of searching radius were applied:

50 m and 100 m These values were considered adequate for this purpose and it has been applied for the same purpose, as Table 1 shows. For example, for the radius of 50 m, this routine led to the identification of 19 HRL.

The *NNH* routine was computed considering several values for the minimum number of points as presented in Table 3. One of these solutions is illustrated in Figure 2.

Table 3. Number of HRL obtained with the NNH routine

Minimum number of road accidents per HRL	5	7	8	10
Number of identified HRL in Vila Real	20	12	9	3

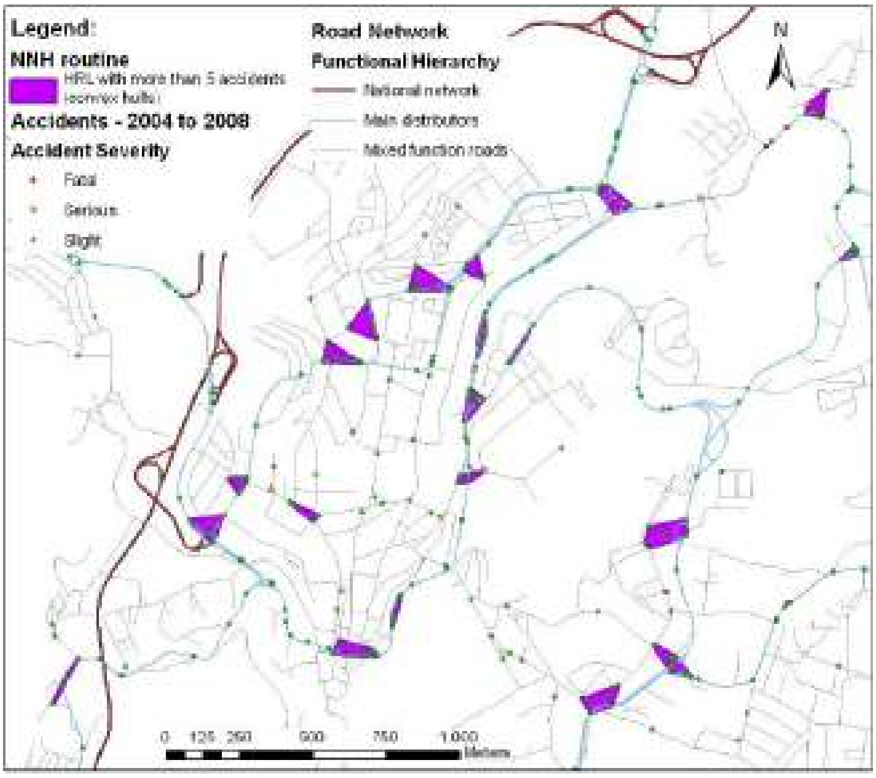

Figure 2. HRL identified with NNH routine

Methods based in density functions

Kernel Density Estimation (*KDE*) was the adopted to identify HRL. This routine requires a set of parameters, displayed on Table 4.

Table 4. Input parameters of KDE routine in CrimeStat®

Parameter	Adopted option
Interpolation function	based on Normal (or Gaussian) distribution
Bandwidth type	adaptive
Bandwidth criterion	minimum number of road accidents of 10, 5 and 3
Cutoff value (density)	0.0002 points/m^2 (corresponds to a 50 m limit away from the road network centreline)
Cell size	10 m

Table 5 presents the number of HRL according to the tested bandwidth values. One of the results is illustrated in Figure 3.

Table 5. HRL identified with *KDE* routine for different bandwidth values

Minimum no. of points to include in the bandwidth	10	5	3
Number of HRL	2	12	28

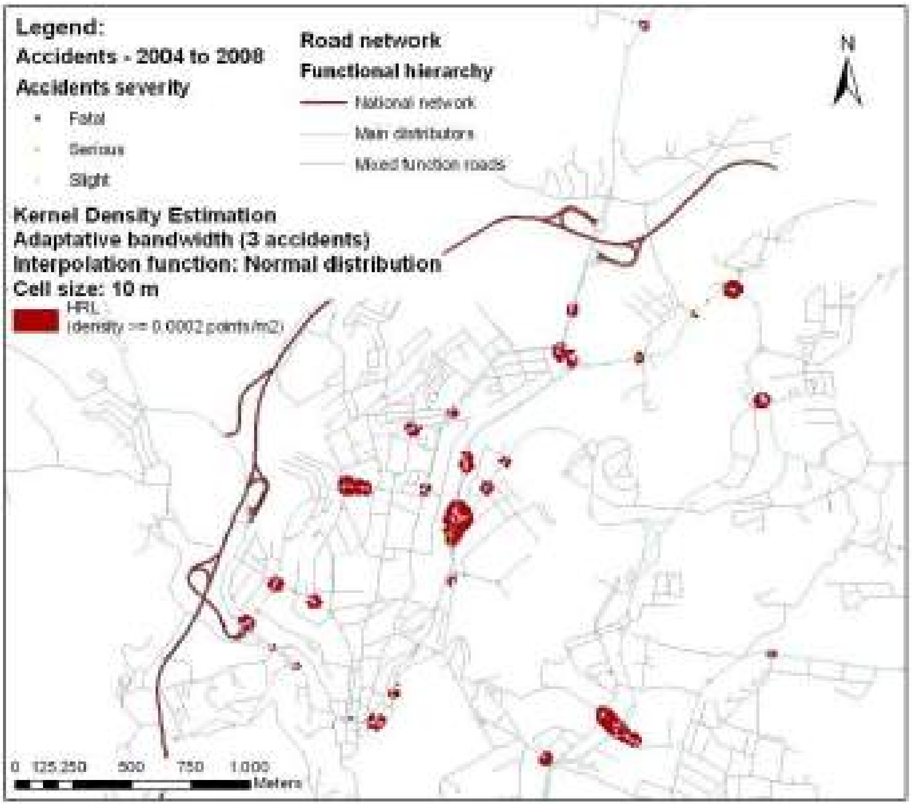

Figure 3. HRL identified with KDE routine
(with a minimum three accidents adaptive bandwidth)

Discussion of results

Results suggest that Method II allows a more accurate reproduction of the selected definitions (see section 2.1) because it considers only an area around the road network avoiding the identification of HRL outside road network, while Method I applies a grid into the entire area, regardless of the road network location. Despite Method II being superior to Method I, it still presents some limitations to the strict application of European definitions (e.g. it applies a searching area instead of a road section). The HRL identified by Method II depend on the definition applied; indeed, some definitions did not identify any HRL (such as the Flemish, Belgian) whereas the Norwegian led to the identification of 25 HRL (see Table 2). This might indicate that some definitions can be more suitable than others to particular city circumstances (from urban layout to data availability). For cities with a larger number of injury road accidents, the Belgian or Flemish definition might be more suitable to identify locations with more severe road accidents, than the remaining applied definitions.

Also, results obtained from the application of different definitions adopted in various countries might be an indication of the road safety performance in each country. For instance, Method II applied to the Norwegian definition led to the identification of more HRL in Vila Real than the remaining definitions. Analyses must keep in mind that results are also dependent on the parameters adopted in Method II, as well as the method itself, which is not an accurate reproduction of the various definitions.

The *Mode* routine reveals low suitability for HRL identification, at least in this case study, because it only identifies locations where road accidents are exactly in the same place (point). Furthermore, its results might be considerably influenced by the georeferencing options that are adopted (e.g. snap the road accident points to the centrelines of the road network and minimum spatial unit used).

Fuzzy Mode routine and Method II showed some similarities, when similar parameters are adopted. It was possible to conclude that, for the same searching area and minimum number of accidents per HRL, Method II identified more HRL than the routine, as it focus the HRL identification process over each point regularly distanced (of 20 m) over the entire road network, whereas the routine only focus over the location of road accidents.

Results show that the *NNH* routine might lead to the identification of HRL which shape corresponds to a long road sections containing a chain of road accidents without length limit. This is suitable for other road safety approaches, such as *route analysis* (CIHT, 1990), but is not adequate for HRL analysis.

Results from the *KDE* routine, show that the specification of the bandwidth has a large influence on the number of identified HRL. Smaller bandwidths might have a tendency to identify more locations.

In general, all methods are relatively simple to apply and require only few calculation minutes; however, other characteristics, capabilities and consequences might influence the choice of a method for identifying HRL and the interpretation of its results. For this reason, a brief comparison was performed between Method II and the *Fuzzy Mode*, *NNH* and *KDE* routines, summarised in Table 6. Method I and the Mode routine were not included in this comparison, as they were considered to perform worse than other essayed methods, as mentioned in this section.

Table 6. Main comparative aspects of Method II and *Fuzzy Mode*, NNH and KDE routines

	Method II	*Fuzzy Mode* routine	NNH routine	KDE routine
Parameters and analysis dependence	Searching radius; Selection criterion; Period of data records; Step of sliding window.	Searching radius; Selection criterion (no. of accidents); Period of data records.	Value of study area; Minimum number of points per agglomeration; Period of data records.	Cell size; Minimum number of bandwidth; Cut-off value; Interpolation function; Period of data records.
Consideration of accident severity	Yes, according to the definition	No	No	No (although possible, not applied in this study)
Some adopted parameters	Time period of accident records; Radius and selection criteria according the applied definition; Step of sliding window: 20 m	5 years of accident records; Radius: 50 m Selection criterion: ≥ 4 accidents with casualties	5 years of accident records; Threshold distance based on a random distribution; Minimum of 5 accidents per agglomeration	5 years of accident records; Cell size: 10 m; Adaptive bandwidth; Cut-off density: 0.0002 points/m^2; Interpolation function: Normal
Shape of HRL	Buffers along the road network centrelines	Buffers along the road network centrelines	Convex hulls	Grid cells with density above the cut-off value

	Method II	*Fuzzy Mode* routine	NNH routine	KDE routine
Main advantages	Allows the definition application; Applies a sliding window; which in the same conditions of *Fuzzy Mode* routine identifies more HRL	Identification HRL centred on road accidents	Requires calibration of few parameters; Identification based on statistical evidence; HRL size dependends on area/number of accidents;	Promotes identification on areas where more road accidents occur (adequate to *area wide analysis* where HRL have to be identified)
Main drawbacks	Results varied according to the applied definition; Implementation proceeding more susceptible to errors: Measurements through Euclidian distance	Choice of search radius and criterion for HRL identification; Measurements through Euclidian distance	Delimitation of the study urban area without considering its shape; Choice of minimum number of accidents in the HRL; Measurements through Euclidian distance	Choice of cut-off value which interferes with the number and shape of HRL; Need of bandwidth determination; Isolated aggregations of accidents have less density value than those surrounded by areas with more accidents.

Although Method II and the *Fuzzy Mode*, *NNH* and *KDE* routines all present advantages and weaknesses, for Vila Real circumstances *NNH* would be a recommendable approach for systematic application.

4.3 Detailed analysis of a hazardous road location

Several locations were identified as hazardous: some of them are consistently recognised by different methods. One of them was identified with seven essays and as it had the highest number of injury road accidents it was chosen for detailed analysis. It corresponds of a road extension of about 250 metres, includes a roundabout and contained 18 road accidents, which 9 are *running over pedestrians* (mainly located over crosswalks) as Figure 4 illustrates.

The analysis of this location was based on stick diagrams (see section 3.4) with the purpose of finding possible problems susceptible of being treated through engineering road safety measures. The analysis of road accidents which often involved one single vehicle (*running over pedestrians* and *run-offs*), indicated a possible problem related to exceeding speed. The analysis of the remaining 9 road accidents did not enable the finding of a common pattern between them which could be indicated as probable causes for their occurrence.

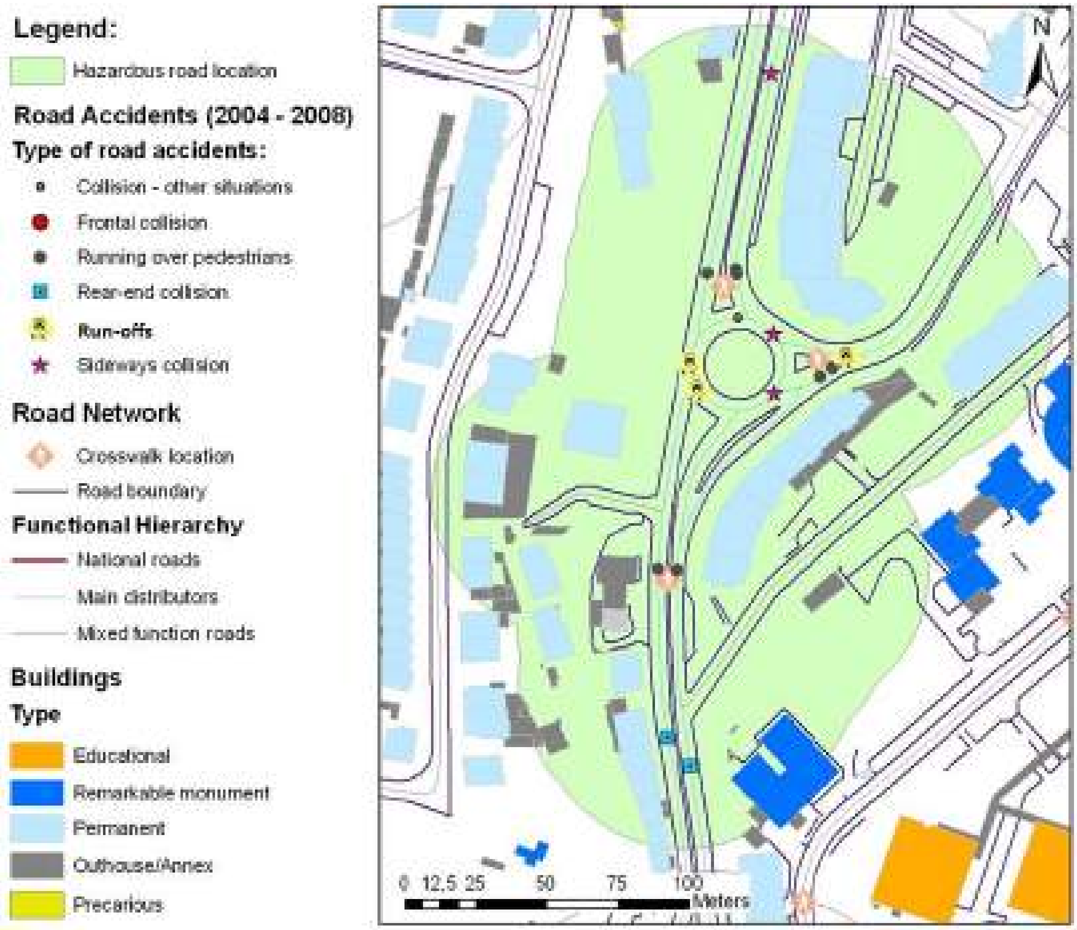

Figure 4. Location of the road accidents in the HRL selected for detailed analysis

The identification of the correct road measure to be applied should take into consideration the safety characteristics and requirements of this site as well as urban function of this area. Possible unwanted side effects of any identified measure, for instance increased noise levels or additional accessibility difficulties for vulnerable road users, must be considered. These sorts of analysis clearly illustrate the multidisciplinary of required working teams including road safety, urban planners and environmental experts.

5. Conclusions and Discussion

The central aim of this work is to compare different methods to identify HRL for which an internationally accepted definition is not available. The treatment of such locations is suitable to be integrated with other types of interventions (e.g., in urban planning) which, for instance, potentiate the optimisation of resources (e.g., in the problem analysis and intervention phases), and promote a wider comprehension of the complex urban road problems in different perspectives which in turn might contribute for integrated/globally better interventions. The work is focused in urban areas taking into consideration the limited resources (including data) that exist in countries where road safety programmes have not been systematically applied. In the scope of this research project different approaches are proposed and implemented: methods I and II and routines *Mode*, *Fuzzy More*, *Nearest Neighbor Hierarchical Spatial Clustering* (*NNH*) and *Kernel Density Estimation* (*KDE*). Spatial analysis software, ArcGIS™ and CrimeStat®, was used.

Results showed that the number and location of the identified HRL in Vila Real between 2004 and 2008 varied depending on the applied method, definition or routine. Amongst all the identified HRL, a considerable number was systematically produced by most methods and/or routines. Results indicate the identification of HRL from 0 for the definitions adopted in Belgium, including Flanders, (reproduced according with Method II) to 28 for the KDE (considering adaptive bandwidth including at least 3 road accidents, the Normal distribution as interpolation function, 10 m cells and a cut-off density value of 0.0002 points/m^2). The differentiation between results also stresses that the establishment of the parameters used in the several methods or routines might influence considerably the identification of HRL. In general, all the methods identified HRL of different sizes and shapes, mostly located on intersections of the highest road functional hierarchy levels suggesting that traffic data would be important to recognise accident rates.

The comparison between methods and their results highlights that *Mode* routine seemed to be inadequate for the HRL identification and Method I showed to perform worse when compared to Method II to reproduce the applied European definitions. The NNH routine is the least dependent from parameters established by the analyst as it has a statistical basis of spatial randomness. However, its calculation does not consider characteristics such as the shape of the area under analysis and relies on the assumption of a homogeneous space (see section 4.2 Discussion of results).

Some of the applied methods and/or routines (Method I and II, Fuzzy Mode, *NNH* and *KDE* routines) consider that space is assumed to be contiguous and homogeneous. This might lead to the identification of HRL containing road accidents that occurred in non-contiguous roads, which is undesirable, as local characteristics might be different from case to case, and the possible underlying problems of road accidents might also be different. Another aspect that should be taken into account in the analysis of the results is the possible error of location of injury road accidents, in particular in the georeferencing process.

To cement conclusion, the implementation to other contexts is recommendable (e.g. larger and smaller cities, with different road accident rates, different types of urban tissues, reflecting its diverse history and complemented with information about *only damage road accidents* as well as exposure data from vehicles and pedestrians).

The suggested methods can be implemented in urban areas in a short term (even if no traffic data is available). Previous studies have demonstrated that perception of the road surrounding influences the road user behaviours which in turn impacts road accident records. Hence, urban interventions should integrate the impact on road safety, in order to improve the entire public space in terms of use and safety. Urban changes should be supplemented with educational, encouragement and/or enforcing road safety measures.

This type of road safety methods/approach is suitable to be integrated with different policies beyond the road safety or oriented to specific targets. Also they might be an important tool to be integrated in a big restructure of a part of an urban area or in other policies, such as: health (promoting safer and pleasant road environment to walk), educational (safety near schools) or intelligent transport systems. Such interventions should include multidisciplinary working teams.

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