ANALYSIS OF TRAFFIC ACCIDENTS SEVERITY IN ALMADA, PORTUGAL USING ORDERED AND UNORDERED RESPONSE MODELS

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ABSTRACT

This study aims at determining the factors that most affect urban road safety in Almada (a municipality located in the Lisbon Metropolitan Area), Portugal, as well as at launching further research that supports safety investment decisions in the face of a limited systematic application of safety measures in the national context. For this purpose, a sample of around 1850 reported injury accidents that occurred in the Municipality of Almada between 2004 and 2008 have been analyzed. The dataset consists of several types of accidents, including those involving pedestrians, both on urban roads and urban/suburban freeways. The available variables cover a wide breadth of aspects that could influence the severity of road accidents. They include: (1) accident specific variables, such as: driver, passenger and pedestrian characteristics, type of maneuver, type of vehicles, weather conditions (2) road specific variables: pavement conditions, functional classification and physical characteristics of the road segment were the accident took place, road signs, (3) variables describing the traffic conditions (e.g. if the accident took place at peak hours); and (4) variables describing the surrounding environment, particularly land use characteristics and patterns.

Both ordered and unordered response models were built to analyze the assembled data. Their results are discussed at two levels. The first is related with the statistical assumptions of the built models, i.e. whether these assumptions are met and, if not, what changes in the models specification are required to overcome the identified issues. The second is related with the policy implications that derive from both models, once statistical assumptions have been met. Functional road hierarchy levels and land use characteristics in the vicinity of the accident, although often overlooked in traditional road safety bibliography, have been found very relevant from an urban road safety planning perspective.

Keywords: Road safety, road accident analysis, ordered response models, unordered response models, Lisbon Metropolitan Area.

INTRODUCTION

Despite considerable progress in recent years, Portuguese road accident rates are still unacceptability high, in particular when compared with other European countries (ITF, 2006). This reduction of accidents has been less noticeable in urban areas. In fact, in Portugal, which has approximately 10 million inhabitants and around 4.5 million registered vehicles, 850 people are reportedly killed in road accidents per annum and around four times as many are seriously injured. Of those, approximately 40% of fatalities and 60% of serious injuries occur within city limits (ANSR, 2008). The fatality records include any person who dies at the scene of the accident or immediately after transport from the scene of the accident. For comparison with information in international road accident databases, and due to the difference in the Portuguese definition of fatal injury used in Portugal and that adopted by the international databases (where fatal injury includes cases where death occurs in less than 30 days as a result of the road accident), Portuguese fatalities figures increase by 14%.

In the past, in countries where road safety has been a priority, a big proportion of the effort and resources assigned to road safety have been directed towards determining which factors are more important in influencing the probability of increased injury severity followed by the implementation and evaluation of measures to correct them. Similar approach needs to be pursued in Portugal.

In safety research from the international standpoint, a large number of studies have shown that accidents, as an aggregate, are systematically over-represented at certain locations and in certain situations. Specifically, the distribution of road accidents on the urban road network tends to be heterogeneous. It has been shown that the distribution and severity of road accidents on the different levels of the functional road hierarchy can differ (IHT, 2008). Also, past research has established that specific locations, such as urban intersections (Al-Ghamdi, 2003;Abdel-Aty, 2005), can be problematic. It has also been widely accepted that there might be stable and marked temporal variations in number and severity of accidents in a region (Levine et al, 1995; Martin, 2002; Shankar & Venkataraman, 2003; Boss et al, 2005). Comparisons of daily cyclic distributions for built-up roads and for different days in the week have contributed to exposing the importance of a further factor in accident occurrence: light and dark (Sullivan and Flannagan, 2002). Another important aspect, extensively analyzed in the literature, is that urban roads do not seem to present similar difficulties for all kinds of road users nor do they offer the same safety standards to all traffic participants. For example, danger on urban roads is increased for pedestrians and motorcyclists (Quddus et al, 2002; Martinez & Porter, 2004). Moreover, historical road accident data, anecdotal evidence and driver self-reports have suggested an over-representation of certain types of driver or rider in road accidents (after allowing for exposure). In fact, the literature also records a large number of research which indicate that driver's age differences are reflected in the type and number of accidents in which they are involved, with the young and the older being often overrepresented (Aguero-Valverde & Jovanis, 2006; Fildes, 2006),OECD, 2006).

Portuguese safety officials do recognize that the urban safety situation is serious and that improvement may accrue from application and appraisal of appropriate engineering, educational and enforcement safety measures directed at factors that affect the risk of increased severity. Yet, only sporadic urban road safety analyzes of Portuguese road accident data have been found in the literature review, and we are unaware of any published application of econometric models to Portuguese road accident data. Neither do national and local administrations, universities and research institutes systematically carry out in-depth road accident data analyzes.

Thus, the focus of this study is on contributing to the reduction in the severity of accidents in Portuguese urban areas by identifying the driver factors, vehicle characteristics, road geometrics and urban conditions on injury severity. Ordered probit and multinomial logit models have been applied to data extracted from individual accident reports in Almada. The difficulty of accessing to data did pose methodological challenges, described in this manuscript, of separating and studying the specific aspects relevant to this particular task. For example, exposure data, including vehicle and pedestrian flows and pedestrian crossing movements at city-wide level, were not available for this study and prevented analysis of risk for different types of factors. Most of the analyses are exploratory as knowledge on the relationship between accident factors injury severity in Portugal is rare. However, results of this paper resemble those of other countries; the key distinction is that here the mix of traffic and urban space functions being performed by different streets are examined and emphasized.

Therefore, while the study dealt with the Portuguese situation, it is felt that the problems and conclusions are relevant for road safety in several other countries, in particular those at similar levels of economic development to Portugal.

The remainder of this paper is organized as follows. Section 2 briefly reviews relevant road safety studies that applied ordered and unordered response models. Section 3 describes the dataset used, and it is followed, in Section 4, by the statistical formulation of econometric model approaches adopted. The following section discusses the results of the estimated models. This paper concludes with an overall summary of models findings and recommendations for future research and practice.

LITERATURE REVIEW

Road accidents are due to a combination of factors relating to the road and the road environment deficiencies, vehicle defects and road users inadequate behavior. Previous research studies have used ordered probit models to study the influence of some of those factors in the probability of sustaining different levels of injury in road accidents.

O'Donnell and Connor (1996), who pioneer the use of econometric models of ordered multiple choice (including ordered probit models) in road accident analysis concluded, for example, that injury severity rises with speed, blood alcohol levels over 0.08% and type of collision. These results have since been expanded beyond this original work (Kockelman and Kweon, 2002; Abdel-Aty, 2003). Other studies focused on the relationship between accident factors and their severity on hazards locations, such as signalized intersections (Abdel-Atry & Keller, 2005), and involving particular types of road users who tend to be over-represented in accident statistics, such as pedestrians (Zajac and Ivan, 2003), bicyclist (Klop, 1998) and motorcyclists (Quddus et al, 2002;Pai & Saleh, 2008). Injury severity of specific type of accidents, such as rear-end collisions (Duncan et al, 2005; Khattak, 1999) and collision with fixed objects (Toshiyuki & Shankar, 2002) have also been analyzed using this technique. In another study, the road speed limits (Renski &Khattak, 2002) have been found important on injury severity. Particularly, it has been suggested that in highway segments where the speed limits has been raised by 10 mph, this has had a higher probability of increased severity than those raised by only five mph. Driver compliance with the Highway Code, specifically the use of seat-belt (Eluru & Bhat, 2007; de Lapparent, 2008), has been associated with the decrease in the probability of severe injuries.

Other authors (e.g. Milton et al, 2008; Hu et al, 2010) have modeled accident severity levels by using unordered response models. The unordered response models although omitting the ordered characteristics of the dependent variable have some advantages since (Milton et al, 2008)

- they are not subjected to inconsistent parameter estimates when there is underreporting in one or more accident severity levels;
- They are not subjected to the parallel regression assumption.

While these techniques have contributed to a growing complexity towards urban road safety, future urban road safety improvements require innovative approaches and depend on the capacity of integrating safety measures and land-use planning policies (28). This study explores the hypothesis that road accident injury levels are affected by both accident-specific variables and urban-specific variables, such as the function of urban roads and land-use characteristics.

DATASET FOR ANALYSIS

The data for the models were obtained for 5 years for the Municipality of Almada, located in Greater Lisbon which is the capital of Portugal. A relational database was assembled with information from three different data sources: road accident data, road inventory and land use data.

Road accident data were obtained for the calendar years 2004 to 2008 from the national database, at Autoridade Nacional de Segurança Rodoviária.

This study utilised information from the national road accident database, for Almada, from 2004 to 2008. The database originally included 1290 accidents which have occurred inside urban areas (The recorded accidents that took place in motorways and outside urban areas were excluded from this analysis). After cleaning for missing data was reduced to 890 reported accidents, of which 12 are fatal 60 serious and 818 slight accident. Accident file records include information on accident time and date, weather, road and light conditions and road characteristics and location. It also contains vehicle and driver details, such as age and gender, and vehicle type with which each individual vehicle collides. Additionally, it includes detail for each casualty such as injury-severity level, age and gender of the victim.

Processes of road data collection and preparation pointed to some particular limitations, particularly, exact location of accidents within the street is often missing from the national database, which restricts the spatial accuracy of accident analysis. Indeed, accidents were located at the mid-point of the street where they occurred. The inference of whether accidents occurred in the daylight or in the dark was reached from the time of the accident. Notwithstanding limitations, the dataset used in the current study was well prepared and adequate for the investigations of the relationships between accident factors and their severity.

It is important to take into account the magnitude and character of the activities that generate the accidents. However, Lisbon Local Authority does not systematically record information on exposure data. Information on road characteristics, urban activity, land uses, population and traffic was gathered from the 2001 national census and from land use databases built based on Points of Interest (POIs) (Rodrigues, 2010.)

Data on urban activity and land uses were assembled from the Census data. The land use variables consisted on density, the total number of inhabitants, workers and students by hectare, the mix between workers inhabitants and students and an entropy indicator measuring the diversity degree of land uses (de Abreu e Silva et al, 2006). The land use variables were collected for a radius of 400 meters around the the mid-point of the street where the accident has occurred

Also, the contribution of inappropriate speed to safety problems (ITF, 2008) as well as variations of traffic volume (Golob et al, 2004) would ideally be considered but this was not practicable in this case study.

All the variables considered in the data set are presented in the following tables.

Table 1 – Variables description

Variable Description	Average	Standard variation
1 if primary route	0.447	0.497
1 if distributor route	0.327	0.469
1 if local route	0.226	0.418
Entropy index	0.221	0.103
Population density	62.012	59.858
Building density	8.023	4.878
1 if daylight	0.776	0.417
1 if Friday or Saturday night	0.067	0.251
1 if Peak Period in the Morning	0.081	0.273
1 if Peak Period in the Afternoon	0.188	0.391
1 if dry pavement	0.852	0.356
1 if wet pavement	0.137	0.344
1 if pavement in good condition	0.591	0.492
1 if good weather	0.892	0.310
1 if one way	0.154	0.361
1 if crossing roads	0.226	0.418
1 if T junction	0.269	0.443
1 if roundabout	0.057	0.233
1 if acceleration lane	0.034	0.181
1 if deceleration lane	0.012	0.111
1 if road section	0.402	0.491
1 if night with illumination	0.033	0.178
1 if night without illumination	0.234	0.423
1 if head on collision	0.163	0.370
1 if side collision	0.319	0.466
1 if rear end collision	0.093	0.291
1 if run off road	0.112	0.316
1 if run over	0.216	0.412
1 if collision with a parked vehicle	0.034	0.181
1 if roll over	0.017	0.129
1 if	0.015	0.120
1 if curve	0.191	0.393
1 if ramp	0.258	0.438
1 if bump	0.006	0.075
number of vehicles involved	1.812	0.676
number of cars	1.442	0.795
number of trucks	0.080	0.291
number of scooters	0.070	0.255
number of motorcycle	0.169	0.383
number of bicycles	0.049	0.222
1 if car involved	0.935	0.247
1 if truck involved	0.074	0.262
1 if scooter involved	0.070	0.255
1 if motorcycle involved	0.165	0.372
1 if bicycle involved	0.048	0.215
1 if only cars	0.651	0.477
1 if car and truk	0.043	0.202
1 if car and scooter	0.061	0.239

Table 2 - Variables description (cont.)

Variable Description	Average	Standard variation
1 if car and motorcycle	0.131	0.338
1 if car and bicycle	0.046	0.210
1 if no car involved	0.065	0.247
Highest alcohol test value	0.092	0.388
1 if alcohol test above legal limit	0.053	0.224
1 if at least one driver without license	0.044	0.205
1 if at least one driver was aged below 18	0.030	0.172
1 if at least one driver was aged between 18 and 24	0.345	0.476
1 if at least one driver was aged between 25 and 65	0.858	0.349
1 if at least one driver was aged 65 or more	0.139	0.346
1 if at least one driver holding a license less than 1year	0.113	0.317
1 if at least one driver holding a license between 1 and 5 years	0.254	0.436
Accident Severity	0.094	0.336

MODEL DESCRIPTION

The dependent variable used in this analysis was the accident severity. This is an ordered variable in which each value corresponds to a certain severity level, although as was stated before it has been treated also as an unordered multinomial variable. Econometric models of ordered and unordered multiple choice are well adapted for dealing with this kind of variables.

An ordered choice model is based on an underlying latent or unobserved variable y* which is specified as a linear function for each observation (Washington et al, 2003; Long, 1997):

$$y^* = x_i\beta + \varepsilon$$

Where xi is a vector of independent variables, is a vector of estimable parameters and e is a random disturbance.

The variable y* is mapped to an observed variable y which is determined as follows:

$$y_i = m \ \text{ if } \ \tau_{m-1} \leq y_i^* < \tau_m \ \text{ for } \ m = 1 \text{ to } j$$

Where are the thresholds or cut points (Long, 1997).

Ordered probit and ordered logit models are two types of ordered choice models. For the ordered probit model, ε is follows a normal distribution with a mean of 0 and a variance of 1 (Long, 1997), whereas in the ordered logit model, e follows a logistic distribution with a mean of 0 and variance equal to π2/3 (Long, 1997). The choice between both models is largely associated with convenience. In the present study, model the ordered probit model was adopted.

In this case, the probability of any observed outcome is given by the following expression:

$$\Pr(y_i = m|x_i) = F(\tau_m - x_i\beta) - F(\tau_{m-1} - x_i\beta)$$

One problem related with the interpretation of results from an ordered choice model is how a certain coefficient influences the intermediate categories of y. For example, it is easy and intuitive to see that a negative coefficient means a decrease in the likelihood in the probability of the higher category and an increase in the lower one. But assuming similar effects in the intermediate category probabilities is abusive. In order to have a sense of the effects direction in the intermediate categories one should calculate marginal effects for each one of the categories in the model. These marginal effects give the direction the probability for each category (Washington et al, 2003) and are obtained by using the following expression:

$$\frac{\partial \Pr(y = m|\bar{x})}{\partial x_k} = \beta_k[f(\tau_{m-1} - \bar{x}\beta) - f(\tau_m - \bar{x}\beta)]$$

The multinomial logit model is given by the following expression (Ben-Akiva and Lerman, 1985):

$$P_n(i) = \frac{e^{\mu V_{in}}}{\sum_{j \in C_n} e^{\mu V_{jn}}}$$

Where V_{in} is the observed part of a utility function U_{in}. It is assumed that the disturbances of the utility function are independently and identically distributed following a Gumbel distribution with a location parameter η and a scale parameter $\mu > 0$ (Ben-Akiva and Lerman, 1985).

The variables defining the utility functions are classified in two groups, the ones that vary across alternatives (or outcomes) and the others, because the multinomial logit is derived using the difference in alternatives, the estimable parameters relating to variables that do not vary across outcomes can only be estimated to n-1 of the functions determining the model outcomes (Washington et al, 2003). This leads that in the present case one of the alternatives has to be normalized to zero so that the model could be estimated.

The described techniques have been used to analyze accident injury severity in the city of Almada.

ESTIMATION RESULTS DISCUSSION

One ordered probit model and one multinomial logit were built their results are presented and discussed. Both models result from the search of the best possible models considering the possible combinations of the variables included in this analysis. Also, since one of the objectives of this study was to find the existence of any type of effect from land use characteristics and functional road hierarchy, it was allowed that variables with associated coefficients with levels of confidence of 70% or more enter in the model.

The first results presented are relative to the ordered probit model and include besides the coefficients and general adjustment indicators the marginal effects and the test for the parallel slopes assumption – the Brant test.

Table 2 presents modeling results for the first model.

Table 3 - Ordered Probit estimation results

Variables	Coefficient	P-Value	Marginal effects: Minor injuries	Marginal effects: Serious injuries	Marginal effects: Fatalitities
Constant	-1.9232	0.0000			
1 if local route	-0.2931	0.0843	0.0312	-0.0261	-0.0051
Entropy index	-0.7615	0.2403	0.0915	-0.0757	-0.0157
Population density	-0.0023	0.0638	0.0003	-0.0002	0.0000
1 if wet pavement	-0.2586	0.2148	0.0269	-0.0226	-0.0043
1 if T junction	-0.2690	0.1155	0.0294	-0.0246	-0.0048
1 if acceleration lane	0.3548	0.2253	-0.0546	0.0435	0.0111
1 if head on collision	0.6984	0.0346	-0.1192	0.0924	0.0268
1 if side collision	0.7705	0.0118	-0.1164	0.0920	0.0245
1 if run off road	1.1430	0.0004	-0.2497	0.1769	0.0728
1 if run over	1.2030	0.0001	-0.2371	0.1724	0.0646
1 if collision with a parked vehicle	1.0478	0.0100	-0.2392	0.1682	0.0710
1 if at least one driver without license	0.6010	0.0268	-0.1073	0.0827	0.0246
1 if at least one driver holding a license less than 1 year	0.3456	0.0619	-0.0509	0.0409	0.0100
μ_0	0.0000	--			
μ_1	0.8836	0.0000			
ρ^2	0.0821				
% of cases correctly predicted		92%			

Brant test

Variables	X^2	P-value
Global	8.5567	0.8055
1 if local route	0.0400	0.8427
Entropy index	0.7000	0.4031
Population density	0.0000	0.9607
1 if wet pavement	0.0000	1.0000
1 if T junction	1.6800	0.1954
1 if acceleration lane	0.0600	0.8110
1 if head on collision	0.4100	0.5222
1 if side collision	0.3200	0.5703
1 if run off road	0.0300	0.8684
1 if run over	0.2300	0.6287
1 if collision with a parked vehicle	0.0000	1.0000
1 if at least one driver without license	0.4700	0.4914
1 if at least one driver holding a license less than 1year	1.8500	0.1739

Since using marginal effects can lead to misleading interpretation when dummy variables are used (Long, 1997), the following table presents the discrete change in probability when each dummy variable changes from 0 to 1.

Table 4 – Discrete change in Probability

Variable	Change	Minor injuries	Serious injuries	Fatalitities
1 if local route	0->1	0.0070	-0.0064	-0.0006
1 if wet pavement	0->1	0.0070	-0.0064	-0.0006
1 if T junction	0->1	0.0066	-0.0060	-0.0006
1 if acceleration lane	0->1	-0.0173	0.0154	0.0019
1 if head on collision	0->1	-0.0494	0.0426	0.0068
1 if side collision	0->1	-0.0587	0.0502	0.0085
1 if run off road	0->1	-0.1245	0.1014	0.0231
1 if run over	0->1	-0.0797	0.0671	0.0127
1 if collision with a parked vehicle	0->1	-0.1047	0.0865	0.0182
1 if at least one driver without license	0->1	-0.0384	0.0334	0.0050
1 if at least one driver holding a license less than 1 year	0->1	-0.0167	0.0148	0.0019

Globally the model results show good prediction capabilities with 92% of cases correctly predicted, although the rho squared is quite small.

The variables selected to enter in this model describe both the land use characteristics in the vicinity of the route segment where the accident took place, its position in the hierarchical organization of the road network, the pavement conditions, the type of intersection, the type of accident and driver characteristics.

Some of these variables were allowed to be included in the model even if its p-value is higher than 10%. Namely some of the variables describing land use patterns, the pavement conditions and the type of road facility where the accident took place.

The results show that accidents involving head on or side collisions, run off road and collision with a parked vehicle tend to have higher severity levels, which is confirmed by the discrete change (Table 4).

The functional hierarchy of routes also influences the severity levels of accidents. Accidents that took place in local roads, where the speeds tend to be lower and they are designed for low capacity levels and high interaction with its surrounding land uses, tend to be less severe. Although the magnitude of discrete change is not high an accident in a local road increases the probability of a less severe outcome while consistently decreases the probability of more severe outcomes (serious injuries and deaths).

Regarding the land use variables the results, although with a p-value of 24% show that accidents that have occurred in mixed urban environments, as measured by the entropy index, tend to have less serious severity levels. Higher entropy index values are an indicator of a more diverse urban environment thus leading to more activities performed on urban streets (more shops, offices and public facilities and public services). This diversity might increase drivers' awareness to their surroundings leading to the adoption of a more adequate behavior.

Also and more importantly, since the p value of the coefficient of this variable is much smaller, accidents in denser areas tend to be less serious.

Density has also a positive influence on the likelihood of lower severity accidents. From analyzes of its marginal effects it is clear that its main effect is to reduce the probability of accidents with serious injuries whist increasing the likelihood of accidents with minor injuries. Remaining marginal effects are null and thus it is possible to conclude that an increase in density tends to increase the likelihood of accidents with minor injuries. Possible explanations could be the higher number of maneuvers (stop and start, parking and occasionally double parking, and turning movements) as well as more conflicts between various road users (drivers, motorcyclists and pedestrians). On the other hand, density might also increase congestion levels which tend to reduce traffic speeds, which in turn can be a deterrent of serious accidents.

The results from the unordered response model (multinomial logit) are presented in the next table. Although they are not directly comparable with the ordered response model since an unordered response model could proliferate parameters (Greene and Hensher, 2008) and the interpretation of its results is different we will compare both models based on the interpretation of expected results from both and mainly considering the land use and road hierarchical level variables.

Table 5 – Multinomial Logit estimates

Variable	Coefficient	P-value
Minor injuries		
Constant	8.2750	0.0000
1 if local route	0.5288	0.1512
Entropy index	1.8450	0.1766
Population density	0.0037	0.1619
1 if daylight	1.0547	0.0582
1 if pavement in good condition	-0.5762	0.0450
1 if acceleration lane	-1.6232	0.0067
1 if run off road	-2.6402	0.0000
1 if run over	-3.1377	0.0000
1 if collision with a parked vehicle	-2.0180	0.0056
1 if bump	-1.9348	0.0645
1 if car involved	-1.2082	0.0541
1 if truck involved	-2.1842	0.0176
1 if motorcycle involved	-1.2582	0.0019
1 if bicycle involved	-0.8805	0.1660
1 if at least one driver was aged between 18 and 24	-1.0106	0.0102
1 if at least one driver was aged between 25 and 65	-1.2390	0.0159
1 if at least one driver holding a license less than 1year	-1.8041	0.0025
Serious injuries		
1 if daylight	1.0830	0.0539
1 if Friday or Saturday night	0.8044	0.1233
1 if crossing roads	1.1468	0.0090
1 if road section	1.1412	0.0018
1 if head on collision	1.3024	0.0368
1 if side collision	1.3379	0.0122
1 if truck involved	-1.0575	0.2789
1 if at least one driver was aged 65 or more	0.7541	0.1341
1 if at least one driver holding a license less than 1year	-1.8617	0.0080
ρ^2	0.14748	
% of cases correctly predicted	0.8617978	

Globally the model results show good prediction capabilities with 86% of cases correctly predicted, with a fairly acceptable rho squared.

The results show that the same land use and road functional hierarchy are also present in this model. Generally they effects could be interpreted as being similar to the ones found in the ordered probit, although they significance levels change substantially. Accidents in local roads and the higher values of population density and entropy index increase the probability of accidents resulting only in minor injuries.

Regarding other variables head on and side collisions increase the probability of serious injuries accidents and run over, run off road and collision with a parked vehicle decrease the probability of an accident resulting in only minor injuries.

This is consistent with the conclusions drawn from the ordered probit model.

Both models point to the pertinence of further research aimed at studying the influence of land use patterns and functional road hierarchy and the resulting road characteristics and configuration. The outputs from the models clearly point to the need, and pertinence, of further tests to developed hypotheses with more comprehensive and detailed data (particularly regarding precise geocoding of accidents locations). The policy relevance of further studies on this subject is important since it can provide important insights both to street design norms and to urban plan measures.

CONCLUSIONS AND RECOMMENDATIONS

This study succeeded in depicting the factors that affect road accidents severity levels in Almada and subsequently suggests approaches to systematically apply safety principles; aiming to contribute toward establishing a basis for policy development, as well as determining clear goals and priorities for further research and practice.

The built models have shown that some of the main accident-specific factors that increase the likelihood of more severe accidents are the type of collision and the involvement of pedestrians (run over). Also the driver's abilities and possession of an adequate license influence the accidents severity levels, as well as the pavement conditions and the type of intersection.

Furthermore, this paper significantly widened the scope of previous safety studies by incorporating variables linked with functional road hierarchy and with land use patterns. Results suggest that urban roads of lower hierarchical levels (local access roads) which cater for local traffic tend to downward accident severity levels. Regarding land use variables, the results showed that they could influence accident severity levels.

Although consistent previous studies, firm quantitative conclusions that road functions and the urban environment has an effect on road safety is difficult to draw due to recognised limitations in this study. Some of the deliberate simplifications adopted here, such as the number of years of accident data, can easily be overcome in further studies with wider coverage. Yet others, like the accuracy and comprehensiveness of accident and exposure databases, will require structural long-term improvements.

Further research on this subject can provide major insights for both urban transport and urban plan policies, which will support the design of predictable infrastructures and complement established engineering, educational and enforcement safety measures in decreasing the number and severity of accidents.

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