LAND USE FACTORS AND THE RISK FOR CHILD PEDESTRIANS

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Abstract: This study investigates the use of land use variables in predicting the number of child pedestrian accident casualties taking Newcastle upon Tyne (UK) as a case study. GIS techniques are used to create spatial models, from which generalised linear models (*GLM*) are developed over all child accidents and KSI (Killed or Seriously Injured) considering the child pedestrian casualty numbers, land use trip attractors and generators as variables. The results show that that secondary retail and high density residential were the main land use types associated with child pedestrian casualties, in such a way that the former was positively associated while the latter had a negative association. It also found that educational sites were also positively associated with child pedestrian casualties, especially for the KSI.

Key Words: *Child accidents, Land use, Generalised linear models*

1. INTRODUCTION

In the Great Britain, the number of child pedestrians killed and seriously injured (KSI) in road accidents has continued to be a significant problem for several decades. As reported by the DfT (2000), road based accidents are the leading cause of accidental injury among children and young people. In 2001, child deaths and serious injuries due to road casualties accounted for 63% of the total child casualties (DfT, 2002). The British government has therefore set a target for reducing traffic related child deaths and serious injuries by 50% in 2010 (DETR, 2000).

According to a recent report by DfT (2005), the number of pedestrian casualties is higher in Britain than most of the European countries. As an early effort, the Britain has launched a programme to develop policies and strategies that would look at the reduction of child casualties for the period of four years in mid nineties (1994-1998) in order to restore parity with the European average in terms of the average number of child casualties. A study that investigated France, Great Britain and the Netherlands as case studies found that children in Britain spent more time near or crossing wider roads or roads with high flows of traffic. They were also more likely to use unmarked crossings and were less likely to be accompanied by an adult (DfT, 2005). In comparison to the OECD member states, Britain is ranked tenth out of thirty seven countries for child pedestrian fatality rates (DfT, 2005). Therefore road safety improvement should be one of the key priorities in Britain for the sake of accident reduction. Safety research is a vital component of road safety initiatives as it can uncover new methods or modify existing methods and propose new areas for prioritisation.

Both motorised and non-motorised traffic are susceptible to road accidents. In terms of road safety, non-motorised users including pedestrians and cyclists, also referred to as vulnerable road users (VRUs), are at risk as they are exposed and unprotected from injury compared to motorised users. One of the most vulnerable non-motorised traffic groups are children because many of them do not know how to behave safely when they are using roads and footways. Therefore, this study focuses on child pedestrian accidents.

Land use as a principal determinant of trips is one of the main influencing factors for road-based environments and related variables including traffic flows, speed limits and pedestrian activities (Lupton et.al, 1999). As reported by Ben-Akiva and Bowman (1995), land use has been shown to be the major factor in generation and attraction of traffic as well as influencing the level of traffic flow, speed and safety. This study therefore attempts to derive a direct relationship between the casualty numbers and the land use type that is responsible for generating or attracting child pedestrian travel. The study carries out an analysis at a higher spatial level looking at aggregation over ward based land uses, hence the detailed road/street level characteristics leading to child accidents do not consider as the main focus of this study. It is hoped that the models would be a tool to estimate accidents at ward level, rather than at a street level, which would follow when certain land use types show strong association to casualties. In general, different land use patterns generate or attract different numbers of trips. A rising number of trips certainly increases the probability of accidents occurring. Therefore, it is reasonable to make an assumption that different land use patterns may generate different accident rates (Wedagama, 2006a).

Many accident studies consider the effect of traffic on the number of child casualties and have successfully shown that more casualties arise from interaction with either busy roads or minor/local/through roads having high speed limits (Christie, 1995; DfT, 2005; Lawson, 1990; Mueller et. al., 1990; Petch, et. al, 2000; Pitt et. al., 1990; Roberts et. al., 1994). However none of them were considered the relationship between child accidents and land use. As an attempt to fill the gap of the existing research, this study investigates the relationship between child accidents and land use.

The prime objective of this study is to investigate child pedestrian accidents and their relationship with land use, which is expected to be a positive contribution to the current safety research in Britain. More explicitly, this study intends to discern the patterns of land use that are highly associated with child pedestrian casualties.

The methodology is developed by the following steps to achieve the goals of this study:

- Preliminary analysis of the child pedestrian casualty data in order to extract information, mainly on the severity of accidents and their locations.
- Application of GIS techniques to develop spatial models that link child pedestrian casualties to urban land use types and administrative boundaries (wards).

- Develop and estimate generalised linear models (*GLM*) to investigate a possible relationship between child pedestrian casualties and land use having land use as predictor variables.
- Investigate the possible contribution of the findings into current road safety policy in the UK.

The city of Newcastle upon Tyne, the major city in the northeast of England, was chosen as the case study area. Several spatial and statistical models were developed in reference to child pedestrian accident data from Newcastle City with special consideration of urban land use patterns and their impact on child accidents, in order to ascertain and propose a possible relationship between them.

2. CHILD PEDESTRIAN CASUALTIES IN THE GREAT BRITAIN

Child pedestrians are generally considered as a part of the non-motorised traffic group. As reported by the DfT (2002), all children below the age of sixteen belong to the child pedestrian category. According to figure 1, there is a considerable reduction in child pedestrians KSI (Killed or Seriously Injured) in the UK during the past 10-12 years. However the number of casualties as recorded (2400 KSI per year) remains a major concern within the road safety agenda in the UK (DfT, 2002).

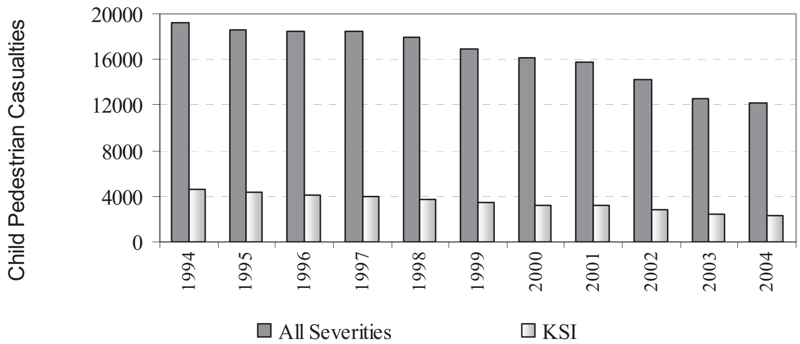

Figure 1 Comparison of child KSI and All accident severities in UK
(Produced using the data from TSGB, 2005)

Studies on child casualties in the UK conducted by DfT (2000) have revealed that the number of casualties increases by age and the teenage children are the most at risk. As shown in figure 2, it is clear that the number of casualties increases steadily for children as they get older. For example, in 2001, the 12-15 age group has an annual KSI rate over four times that of the 0-4 age group and over three times the casualty rate for slight injuries. Over the period of 1996-2001, there has been a decline in KSI and slight injuries for all ages. However, for the age group 8-15, the decline is at a slower rate than that for young children. The DfT (2003) has found that child pedestrians who face the most risk are boys. Similarly, children from low income families, ethnic minorities, as well as the children living in old terraced houses on straight roads are more vulnerable for traffic casualties.

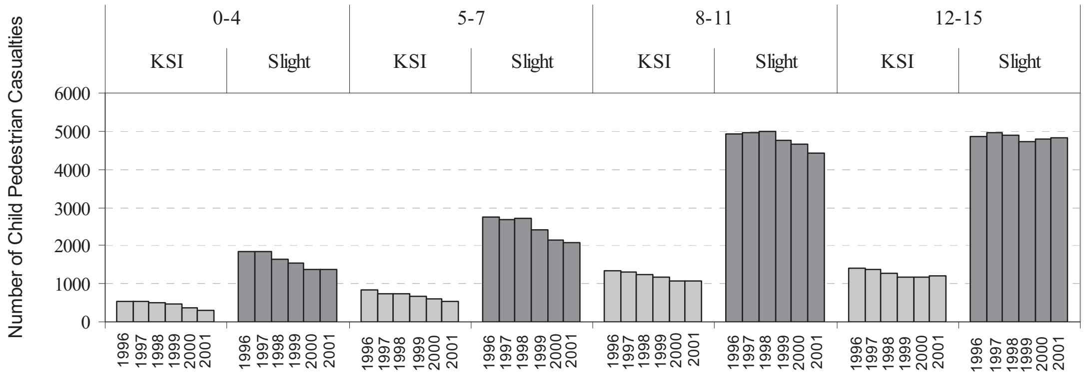

Figure 2: Child accident severity by age in Great Britain
(Produced using the data from DfT, 2002)

3. MODELLING LAND USE AND PEDESTRIAN CASUALTIES

Pedestrians move from one place to another in order to satisfy their requirements, and therefore the demand for transport is always considered as derived. It therefore seems reasonable that land use and transport may have some interactions between them.

3.1 Modelling Land Use and Spatial Characteristics

A recent paper by Rodrigue (2006) explained that the transport-land use system can be divided in three sub-categories of models: land use, spatial interactions and transportation network models. Accessibility and mobility both have impacts on travel where land use patterns in an urban area determine how people access services (Litman, 2003). Mixed land use generally improves accessibility and provides safe travel for pedestrians. This has a positive effect on the number of casualties occurring in an area. Badruddin and Herrington (2006) define a spatial model as a geographic/spatial data manipulation and analytic process that facilitates the production of information to solve complex problems. The spatial modelling process consists of a number of steps: problem-identification, simplification, organizing data, preparation of a logical flowchart with clear and defined operations, data analysis, and modification or correction of errors as required Badruddin and Herrington (2006). Although the procedure suggested is suitable for the analysis of environmental or geographical data, the output of the spatial model can be used as input for the accident modelling (Wedagama, 2006a).

In order to carry out spatial analysis, Geographical Information Systems (GIS) techniques are particularly useful. Tortosa (2000) describes GIS as computer software and hardware systems that enable simulation and advanced analysis of geo-referenced data to manage information that enables decision making. Foote et al. (2000) explained the manipulation abilities of GIS which involve the separation of information in layers and various combination models. A stack of map layers can be obtained using GIS methods where each map extracts different level of information starting from the base map (Foote et al., 2000).

3.2 Modelling Pedestrian Accidents

Accidents are always discrete events resulting in non-negative values. This sort of data is generally analysed using a number of methods including the *Poisson*, the *Negative Binomial*, and the *Bernoulli methods*. In the situations when the data contains many zeros, the accident modelling has to be conducted by the *Zero Inflated Poisson (ZIP)* and the *Zero inflated*

Negative Binomial methods (ZINB) (Lord et al., 2004; Shankar et al., 2003; Lee and Mannering, 2002).

Many accident studies have used the *Poisson Regression* (Wedagama, 2006a; Mountain et al., 1996; Famoye et al., 2004; Sideris et al., 2005; Kweon, 2003). The *Poisson distribution* has characteristics of being skewed and non-negative where the data is assumed to have a variance that increases with the mean. The *Poisson Regression* generally uses a log transformation to cater for the skewed and non-negative characteristics of data (Simon, 2006). In contrast, traditional *Ordinary Least Squares Regression* assumes a normal distribution of residuals, produces negative values, and assumes a constant variance (Simon, 2006). The assumptions of equal mean and the variance of events in the *Poisson distribution* sometimes make it unsuitable for real life situations as there is a possibility of under-dispersion and over-dispersion. When the variance is larger than the mean (over dispersion) or smaller (under dispersion), it indicates that *Poisson distribution* does not adequately fit the analysis (Simon, 2006). In such cases, the *Negative Binomial Distribution* is used as a generalisation of the *Poisson distribution* as it does not assume equal chance or randomness for all elements in a distribution e.g. the chance of casualties in one ward may be higher than in another ward (Simon, 2006).

A number of studies have used the *GLM* (Wedagama, 2006a and 2006b; Famoye et al., 2004) to model casualty data. The *GLM* can be used to confront linear and non-linear effects of continuous and categorical predictor variables on a discrete or continuous dependent variable.

4. CASE STUDY AREA

This study investigates data from Newcastle upon Tyne. This city is the regional capital of the northeast of England with a very vibrant, competitive but friendly environment. Newcastle district belongs to the Tyne and Wear conurbation, which comprises Newcastle and North Tyneside to the north of the River Tyne, Gateshead and South Tyneside south of the Tyne, and Sunderland located to the south at the mouth of the River Wear. Newcastle upon Tyne was historically a coal mining area. Like many English cities, it is making efforts to recover from the legacy of industrial change, and compared with many, it has remained disadvantaged. These facts are recognized by Newcastle City Council, which plans to continue developing the city to one where people have access to a more prosperous, healthier, safer and sustainable life style in an attractive environment.

Like most UK cities, Newcastle experiences significant localized congestion at key locations in its central business district. Thus one of the challenges is to reduce the level of traffic congestion. Car ownership in Newcastle and the north-east region has remained lower than the national average. However the potential for car ownership growth in Newcastle in the future is high and it is now increasing at twice the national average. The city covers an area of 113 km^2. As of 2001 Census Data, it has a population of about 259,536 of whom 48,720 are children under 16 years of age representing 18.8% of the population (National Statistics, 2001). Newcastle district consists of 26 wards, 11 of which are shown in figure 3 below that are closest to the city centre. The most populated ward is Dene with approximately 6% of the total population, while the lowest is West City ward with 2.4%. In terms of child population the highest and lowest wards are as with the total population above, with percentages of 6% and 1.8% respectively. Newcastle district has a total of 99 schools attended by 37,000 pupils.

Figure 3: Case study area –the city of Newcastle upon Tyne

5. MODELLING APPROACH

This study proposes an integrated modelling approach to deal with spatial interaction as well as child pedestrian casualties in order to accomplish the task of investigating land use impacts on child pedestrian accidents. At first, spatial land use/accident interaction models were analysed to generate necessary land use outputs. Next, the land use outputs from the spatial models were used as inputs in the child pedestrian casualty modelling in order to identify the relationship between land use and casualties.

5.1 Spatial Model

A spatial model is developed to assign child casualties to specific land use types in specific wards of Newcastle district. The model should fit the following criteria:

- Child pedestrian casualties are geographically referenced
- Newcastle district area defined with ward boundaries
- Land use classification of Newcastle district defined (and referenced to ward boundaries)
- Child pedestrian casualties identified with specific land use and ward

The expected outputs of the model represent the proportion of independent variables (land use types) and casualties per spatial unit. The required data sets for this model are the baseline map for Newcastle upon Tyne, geo-referenced child pedestrian casualties and land use data for the area. Figure 4 shows the flow chart of the model development process.

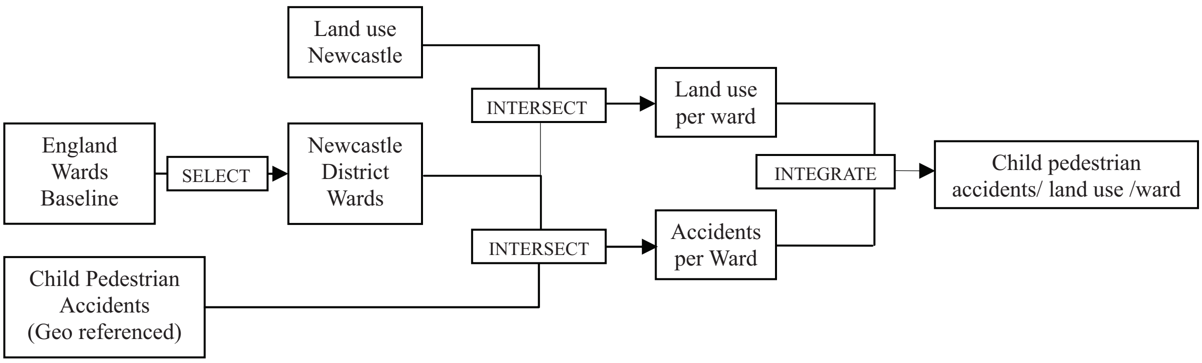

Figure 4: Flow chart for the spatial modelling process

5.2 Accident Model

The *GLM* technique is selected in this study due to its applicability over the normalization facility of non-linear data. The response or the dependent variable can be non-normal, and does not necessarily have to be continuous.

In linear regression models, a dependent variable *Y* is linearly associated with a series of independent of explanatory variables (*X*).

$$Y = \beta_0 + \sum_{j=1}^{P} \beta_j X_j + \varepsilon \qquad (1)$$

Where

Y: dependent variable (Child pedestrian casualty)

X: explanatory variables (road length, junction density, land use type)

β: unknown parameters

ε : error term

The expected value of *Y* can be calculated by,

$$E[Y] = \mu = \beta_0 + \sum_{j=1}^{P} \beta_j X_j \qquad (2)$$

In the *GLM*, the relationship between *E*(*Y*) and *μ* is specified by a non-linear link function called g(μ), and it can be in any form of *Poisson, Normal, Gamma, Inverse Normal, Binomial, multinomial distributions*.

$$E[Y] = g(\mu) = \beta_0 + \sum_{j=1}^{P} \beta_j X_j \qquad (3)$$

The link function for *Generalised Linear Poisson Regression* is specified as:

$$Ln(\mu) = \beta_0 + \sum_{j=1}^{P} \beta_j X_j \qquad (4)$$

In order to estimate the *GLM*, the values of the parameters (β_0 through β_j and the scale parameter) are obtained by maximum likelihood estimation (MLE).

Basically, the *GLMs* are developed to predict the child pedestrian casualties that can be expected to occur for a given proportion of land use type. In order to obtain a valid model, a number of criteria have to be met such that it can be relied upon for the real world application.

The following criteria will be pursued in development of the model:

- Logical output results
- Consistency and robustness

In order to estimate the *Generalised Linear Poisson Regression* (*Poisson GLM*) models using MLE methods, the models should meet the following criteria:

- The ratio of the Poisson deviance to degrees of freedom or Pearson chi square to degrees of freedom should be approximated to 1.
- The predicted coefficients should have significant z-score probabilities at a confidence level of p=0.05.

Negative Binomial Regression models are used when the result for the *Poisson GLM* shows over dispersion. Use of the Maximum Quasi Likelihood (MQL) estimation to optimise the deviance has been found to solve this as well when using S-Plus (Shankar et al. 1997). In the case of *Negative Binomial (NB) Regression*, the Likelihood Ratio (LR) test is used to determine suitability of the regression to model the data. For this test, the value if α=0, the *NB Regression* equals the *Poisson Regression,* otherwise its probability should be significant at a p=0.05 confidence level.

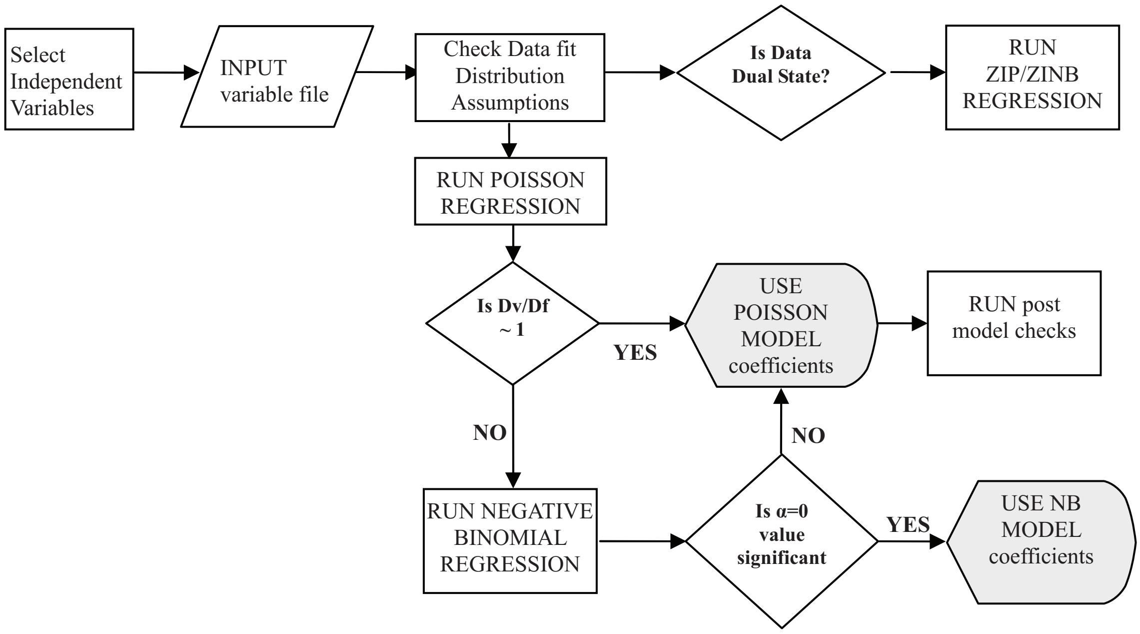

Figure 5: Flow chart for the *GLM* model (Poisson Regression/Negative Binomial)

6. DATABASE STATISTICS

6.1 Child Casualty Data

The child casualty data was obtained as secondary geo-referenced data from the Traffic Accident and Data Unit (TADU) of Gateshead Metropolitan Borough Council (MBC). It consists of details of child casualties that took place between the years 2000 and 2005 inclusive, showing the time of occurrence, day and date of accident, location information including easting and northing, number and description of casualties, road classification details, vehicle details, and other related information. It was collected for the area between the Ordnance Survey coordinates [421,500E, 563000N] for the top left corner and [428000E, 569000N] for the bottom right hand corner. Each accident recorded has a unique location defined by its coordinates and this feature is used to link the accident as a point to the map and the land use data of the city.

The data obtained from Gateshead MBC consists of child casualties that occurred in Newcastle upon Tyne between January 2000 and December 2005. There are 522 casualties recorded. Figure 6 below shows the distribution of the casualties.

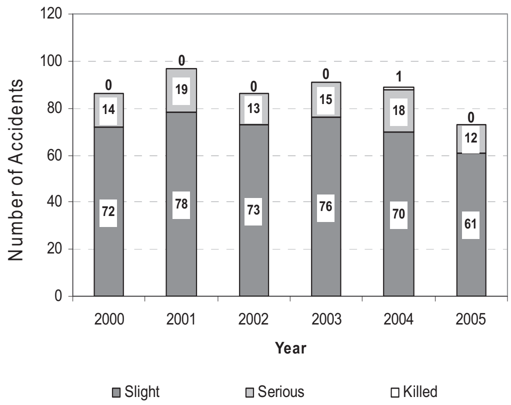

Figure 6: Child pedestrian casualty distribution in Newcastle during 2000-2005

The average annual number of casualties for the six-year period is 87 while that for KSI was 15. It is noted that the years 2000, 2002, and 2005 had casualty numbers below the average. There is an 11.5% increase in child casualties in 2001 above the average, and a 16% reduction below the average in 2005. The majority of the casualties (83%) resulted in slight injuries and there was only one fatal accident. Of the 522 casualties in the data, 320 of them are male, while 222 are female. This could probably be due to the higher mobility of boys compared to girls, which leads to more exposure of boys to traffic and hence casualties. This trend was also observed in other literature (DfT, 2003).

According to the data, the lowest number of casualties occurred on Sunday representing 7% of the casualties, and the highest on Friday, representing 18% of the total casualties. There is a gradual increase in casualties noted from Sunday to Friday, with a slight drop in the midweek period. This trend could stem from the mobility patterns of the children. Whereas they travel on weekdays to school and other places after school on their way home, they are likely to travel less on weekends especially on Sunday and stay home with their parents. Alternatively, it could be that they are less likely to be accompanied by an adult everyday when they travel to and from school, while at weekends, they will have an adult accompany them when shopping or going for leisure activities. Hence mobility may not necessarily have decreased significantly at weekends, but rather the safety and awareness of their travel varies.

Most of the casualties occurred in the hours 08.00–09.00 and 15.00-16.00, and there is a reduction of recorded numbers from 16.00 to 20.00. A typical school day generally lasts from 8:30 to 15:30. It appears that these casualties occur mainly at times when the children are coming to and leaving school. There is also a significant number of casualties that occurs outside these hours, and even some extreme cases between midnight and 02.00 in the morning.

The casualties are most frequent in the West City ward (9%) and least frequent in Jesmond ward (1%). West city is the ward in which the city centre lies and many casualties are observed to occur in the area consisting of primary retail and “class-A” roads. This could imply that this area is a major trip attractor for the children. The casualty distribution in Newcastle is analysed and represented in figure 7.

By carrying out spatial analysis with Arc Toolbox, the kernel density of the accident points is calculated to reveal areas with a higher density of casualties or spatial clusters. These clusters occur in the area in and around the city centre that has a relatively higher concentration of retail, leisure and residential land use as well as road length. Two thirds (66%) of the casualties occurred whilst the children crossed at points more than 50 metres away from the designated pedestrian crossing. A significantly high number (10%) also occurred on the pedestrian crossing itself.

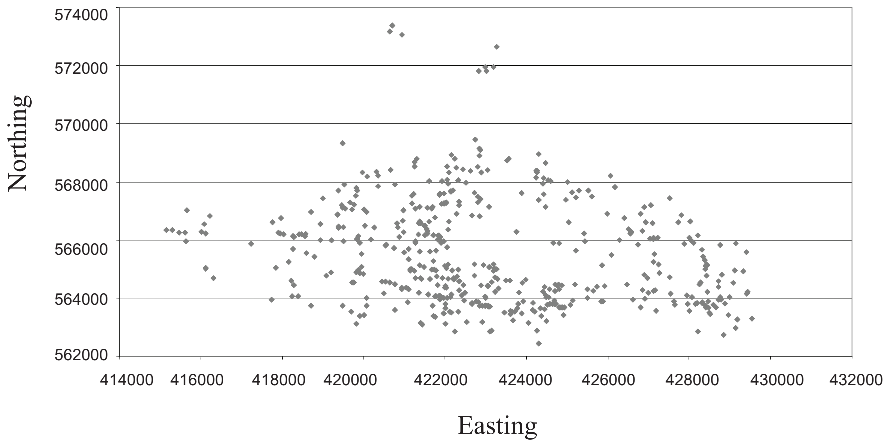

Figure 7: Child pedestrian casualty distribution in Newcastle during 2000-2005

6.2 Land Use Data

Land use data was obtained in the secondary form from the School of Civil Engineering and Geosciences at University of Newcastle, Newcastle City Council, and EDINA Digimap of Edinburgh University. It consists of details of land use classification of Newcastle city as defined by the Office of the Deputy Prime Minister (ODPM), (now the Department for Communities and Local Government (DCLG)). Classification types include residential, transport, utilities, industry, commerce, community services and vacant land. A map from UKBORDERS on the EDINA portal is also available with the smallest electoral unit of division, a ward, for the Newcastle area. Land use data for Newcastle were obtained as AutoCAD shape files (.shp extension), datacard layer files (.lyr) and dbase files (.dbf). The format of the data makes it suitable for viewing with GIS software such as ArcGIS and ArcView 3.1. The dbase files contain tables and can be edited with MS Excel and MS Access.

It has been mentioned in the literature above that use of some variables may result in multicollinearity due to inherent similarities or correlations between the predictor variables. Therefore some measure of correlation between predictor variables is warranted to avoid duplication of effects in the model by highly correlated variables, which leads to misleading results. The Pearson coefficient of correlation is calculated for all the land use types as shown in the table 1 below.

From Table 1, it is noticeable that some variables are correlated. Residential and community buildings are expected to be highly correlated to child population density in that it is expected to be high in areas with a lot of residential land use and lower in low residential land use. The correlation matrix above though shows a moderate correlation between these two variables. Variable selection also takes into account the trip attractors and generators for child pedestrians so that it is logical to say that the land use is a contributory factor to child pedestrian casualties. Therefore not all variables should necessarily be used in the model, particularly industrial and storage (IS), offices (J), vacant land (V), footpaths (W), and Transport (T). As some correlation occurs between these variables as shown above, a few variables are then selected as trip attractors and trip generators. The models therefore consider road length (rl), community buildings (c), primary and secondary retail (pk, sk), both high and low density residential (hd, ld), open spaces (o) and educational sites (es) as predictor variables.

Table 1 Correlation of essential land use variables

	cpoD	ALL	KSI	c	es	hd	ld	o	pk	sk	jd	ln(rl)
cpo	1											
ALL	0.16	1										
KSI	0.04	0.81	1									
c	0.75	0.28	0.58	1								
es	0.14	0.28	-0.05	0.25	1							
hd	0.42	-0.45	-0.11	0.16	-0.11	1						
ld	0.40	-0.10	-0.35	-0.05	0.48	0.24	1					
o	-0.31	0.02	-0.14	-0.05	0.08	-0.39	-0.02	1				
pk	-0.55	0.52	0.49	-0.28	-0.36	-0.42	-0.63	0.09	1			
sk	0.74	-0.06	0.27	0.41	-0.48	0.62	0.07	-0.32	-0.22	1		
jd	0.08	-0.16	-0.17	-0.26	-0.31	0.06	0.44	-0.34	-0.13	0.15	1	
lnrl	-0.43	0.16	-0.02	-0.08	0.12	-0.23	-0.33	-0.16	0.34	-0.38	-0.02	1

c	Community buildings	ld	Low density	sk	Secondary retail
es	Educational sites	o	Open spaces	jd	Junction density
hd	High density	pk	Primary retail	ln(rl)	Ln (road length)
CpoD	Child population density	ALL	All child casualties	KSI	Killed or seriously injured

7. MODEL ESTIMATION, RESULTS AND DISCUSSION

The *GLM* models were developed considering the casualty types and temporal variations in Newcastle city for the period of 2000-2005. Ten out of eleven wards in Newcastle district were incorporated in the analysis. Heaton ward, in particular, wasn't included in the analysis due to land use data limitations. Also, it is mainly a residential locality and as a result, it is well facilitated with traffic calming schemes. Therefore, including it in the analysis may generate some biases in the model outputs. Table 2 below explains the models developed.

Table 2 A Summary- the GLM models developed

Model	Casualty regime	Data type	Time period	Predictor variables
1. ALL	All casualties	ALL	All year	es, jd, hd, ld, pk, sk
2. KSI	KSI	KSI	All year	es, jd, hd, ld, pk, sk

7.1 Offsetting Road Length in the GLM Models

Road length is a factor that is directly related to road casualties, in that if there are no roads in an area then there would be no road casualties. As the road length increases, the exposure to traffic increases providing an increased chance of an accident occurring. This implies that a ward with a greater length of road has more probability of child pedestrian casualties, and thus appear that such a ward has a higher risk. To remove this effect, the model was developed to adjust for this effect by offsetting the road length, where the road length variable enters on the right-hand side of the equation, but with a parameter estimate constrained to 1.

$$Ln(\mu) = Ln(rl) + \beta_0 + \sum_{j=1}^{P} \beta_j X_j \tag{5}$$

It implies, $Ln\left(\mu / rl \right) = \beta_0 + \sum_{j=1}^{P} \beta_j X_j$ (6)

Therefore, the *GLM* equation can be written as:

$$Ln(\mu) = Ln(rl) + \beta_0 + \beta_1 jd + \beta_2 es + \beta_3 hd + \beta_4 ld + \beta_5 pk + \beta_6 sk \tag{7}$$

7.2 Outputs of the Spatial Model

As explained in figure 4, the spatial analysis was conducted to obtain child pedestrian accidents per land use type for each ward (table 3).

Table 3 Spatial model output for selected wards

Ward	ALL	KSI	Land Use Proportions (%)								jd /km	Ln(rl)
			c	es	hd	ld	o	pk	sk	other		
Byker	13	4	0.057	0.595	2.706	3.827	3.910	1.569	1.022	86.314	7	3
Dene	24	3	0.123	10.47	2.049	24.50	19.83	0.000	0.407	42.613	6	4
Elswick	36	8	0.219	4.724	15.92	21.03	5.628	0.000	1.842	50.628	7	3
Jesmond	6	0	0.000	6.272	19.77	26.52	6.914	0.000	0.945	39.577	6	3
Kenton	38	3	0.022	9.865	0.233	35.06	22.59	0.000	0.429	31.794	7	3
Moorside	23	4	0.060	1.525	3.206	2.392	43.81	6.214	0.821	41.972	5	3
Sandyford	9	0	0.033	1.973	12.27	9.529	13.36	0.000	1.098	61.728	7	4
South Gosforth	11	1	0.000	0.525	9.711	40.80	16.75	0.000	1.381	30.820	10	3
West City	47	7	0.000	2.172	2.240	4.080	5.398	11.73	0.852	73.525	7	4
Wingrove	28	4	0.082	4.342	9.464	23.80	17.57	0.000	1.700	43.041	5	3

ALL	All casualties	hd	High Density	sk	Secondary Retail
KSI	Killed and Seriously Injured	ld	Low Density	jd	Junction Density per km
c	Community Buildings	o	Open Spaces	ln(rl)	Natural log of Road Length
es	Educational Sites	pk	Primary Retail	o	Open Spaces

The variables for community buildings (c) and open spaces (o) are not considered for the modelling process because the number of predictor variables would in that case be 9 for the 10 wards being observed in the study. This is avoided as models obtained might be over-fit because of only one degree of freedom (Chong, 1997). These are removed and the resulting models have 3 degrees of freedom which is considered sufficient for the modelling.

7.3 Estimation of an Accident Model

A commercial statistical software package Stata v7.0 is used to estimate the models. It was used to obtain the Generalised Linear Poisson Models using maximum likelihood estimation (MLE), as well as to obtain the Negative Binomial regression models. Before running each model, assessment of the data was first done using methods of descriptive statistics such as obtaining the mean and variance, histogram, box plots, and normal curve plot to check for consistency with the assumptions of the Poisson distribution. The modelling process was then carried out. The results of the initial modelling process are shown in the Table 4 below.

Table 4 Determination of model fit

No	Casualty model	Explanatory variables	Deviance/ Deg. of Freedom (dv/df)	Test statistic	Best model
1	ALL	es, hd, ld, pk, sk, jd	14.59276	LR test for NB: $\chi 2 = 20.54$, p=0.000. Significant at p=0.05	Negative Binomial
2	KSI	es, hd, ld, pk, sk, jd	3.650512	LR test for NB: $\chi 2 = 0.00$, p=0.5.Not significant at p=0.05	Poisson

From the above table, the overall child casualties' (ALL) model could be best modelled using the Negative Binomial regression. For the KSI model, Poisson regression was used in the analysis. Having selected the regressions to apply, models were then evaluated to determine the coefficients estimated for the land use types that would be expected to significantly affect the number of child pedestrian casualties in a defined administrative area. The table below shows the results of the coefficients estimated for each model. Estimation results of the above models are tabulated in the Table 5.

Table 5 Accident model output

Variables	ALL		KSI	
	Coef.	*t*-stat.	Coef.	*t*-stat.
1	-1.50	-1.13	**-7.09***	-2.92
es (educational sites)	-0.11	-1.38	**0.28***	2.06
hd (high density)	**-0.10***	-2.79	**-0.24***	-2.51
ld (low density)	0.02	0.87	-0.06	-1.56
pk (primary retail)	0.08	1.39	-0.01	-0.19
sk (secondary retail)	**1.72***	3.34	**3.98***	3.32
jd (junction density)	-0.12	-0.71	0.30	1.17
Summary statistics				
Number of casualties	235		34	
Number of wards	10		10	
dv/df	14.59		3.65	
Model type	Negative Binomial		Poisson	

Notes:
Bold figures are significant at *95%.

8. RESULTS AND DISCUSSION

From the above table, it is observed that secondary retail and educational sites are positively associated with child pedestrian casualties of different severities, while high density residential is noted to have a negative association. A negative association implies that as the land use increases, the occurrence of child pedestrian casualty decreases, while for a positive association, the reverse is true. The land use data available was only for 10 of the 26 wards in Newcastle and therefore casualties occurring in wards without available land use data were left out, which led to limitation of variables used. Dissaggregation of some of the land use data such as educational sites would probably have improved the models' sensitivity as well. Also the model requires more variables to allow for reduction of casualties predicted in situations where area wide traffic calming schemes or increased road safety education has been provided as well as other casualty reduction strategies. Inspite of these short comings, the models provide reasonable estimates and have the ability to predict casualties for different time periods. The findings of this study are tabulated in Table 6.

Table 6 Results obtained from the models

Accident Model	Land use predictor
ALL	**High density (-)**, **Secondary Retail (+)**
KSI	**Educational sites (+)**, **High density (-)**, **Secondary retail (+)**

Note: Land use shown in bold format is significant at 95% level of confidence.

8.1 Effect of Secondary Retail

Both models (ALL and KSI) predicted that secondary retail (sk) is positively associated with child casualties. This land use type occurs away from the city centre in the neighbourhoods of many residential areas. It also consists of supermarkets out of the city centre, grocery stores, etc. It is a trip attractor for child pedestrians as they go to the shops to buy snacks, play toys, and games. In general, secondary retail shops and stores are located along through roads, and therefore road safety issues are a concern here. Because some retail streets only provide on street parking, these could be a problem for child pedestrians as they have to cross crowded streets. The positive association therefore does make sense. It was expected that primary retail would also have a significant positive association with the child casualties, but the model explains this differently. The insignificance of primary retail may be a result of few observations. Only 3 of the 10 wards whose land use data was available in a sufficient amount had primary retail. A better picture would probably be obtained if all 26 wards of Newcastle were assessed, so as to provide a more conclusive decision.

8.2 Effect of High Density Vs Low Density Residential Land Use

A trend noticed from the 10 wards is that they typically have more low density percentage land use than high density. Correlation of the variables, as shown in table 1 above, show that child population density has a fairly negative correlation with both high and low density land use, with a slightly higher correlation to high density than the latter. The models also showed that low density residential areas are not significantly associated with child pedestrian casualties. Therefore the road layout and road environment features with pedestrian friendly facilities (side walks, crossings etc) in high density residential areas could be a possible cause of this association. Whereas the scope of this study did not involve assessment of the road network structure for each land use type used in the analysis, this could be an important issue for further study to see what contribution it makes to the casualties observed.

8.3 Effect of Educational Sites

Another land use type that would have been expected to have a positive significant influence on the overall number of casualties is the educational sites. For this study these include all schools, colleges and universities and libraries in a ward, as the data provided was not disaggregated to a level where sites that would typically attract children below the age of 16 would be the only ones included. This therefore might have affected the sensitivity of the model to the schools' land use proportion. On the other hand it is likely that some of the casualties which occurred in wards with a small number of educational land use proportion were due to other factors. Wards such as Byker, Moorside and West City, whose proportion of educational land use is comparatively low in the 10 wards, had high accident counts, while Jesmond, whose proportion of similar land use is high, had the lowest number of casualties. The KSI model predicted that child KSI casualties are associated with educational sites.

8.4 Contributions from this Research to the Current Road Safety Policy in the UK

Current road safety policy, namely DfT's Road Safety Strategy (DfT, 2000) and the Action Plan Report of the Road Safety Advisory Panel (RSAP) (DfT, 2002), requires Local Authorities to perform child road safety audits in order to collect information on child casualties, devise means of addressing their causes and monitor the progress of the schemes in regard to reduction in severity and number of casualties. It also empowers them to create more speed limit zones, introduce more traffic calming measures and pedestrian crossings and to develop and implement school travel plans (DfT, 2000). Unfortunately Local Authorities are finding it hard to implement this. It was found that the models could assist in carrying out child road safety audits as their methodology provides a starting point by identifying areas that are likely to be associated with high incidences of child pedestrian casualties. The Local Authorities can then focus on these areas and carry out detailed analyses.

9. CONCLUSIONS

The UK road safety strategy of 2000 recognises the contribution that child road safety research makes to development of accident reduction initiatives. It is with this motivation that this study was carried out. The objective of the study was to obtain a relationship between urban land use and child pedestrian casualties in Newcastle District, located in the northeast region of England. The study also set out to characterise the spatial variation of land use and child casualties as well as investigate their temporal characteristics. *GIS* techniques and *GLM* modelling methods were used to derive and analyse the occurrence of child pedestrian casualties at the ward administrative (and geographical) level.

Spatial models were created that associated child pedestrian casualties to the land use classification types that constitute their typical trip attractors and generators. By using the developed spatial models, two statistical models were developed that predict the casualties depending on the proportion of land use types and junction density, whilst offsetting the effect of road length. The results show that that secondary retail and high density residential were the main land use types associated with child pedestrian casualties, in such a way that the former was positively associated, while the latter had a negative association. A positive association implied that increase in the proportion of this land use type would appear to result in more casualties, whilst for negative association, the reverse was true. It also found that educational sites were also positively associated with child pedestrian casualties, especially for the KSI.

This study also compared the findings to current UK road safety policy contained in the Road Safety Strategy 2000 contained in *Tomorrow's Roads Safer for Everyone*, (DfT, 2000), and the Road Safety Advisory Panel (RSAP) Action Plan on Child Road Safety *Child Road Safety: Achieving the 2010 Target* (DfT, 2002) and found them to be in line with current strategies. It was also found that the study methodology could to be useful in performing Child Road Safety Audits, which the Road Safety Strategy requires Local Authorities to perform periodically, by identifying key areas to focus the audits. Limitations of the study included the small number of wards with available land use data which restricted the number of variables used as well as the models' sensitivity, and the level of disaggregation of the data, which limited the application of further regression techniques and post modelling tests.

Nevertheless the study finds that association of land use to child pedestrian casualties can reveal important linkages whose underlying characteristics are likely to be causative factors of such casualties. It performs a mesoscopic level accident analysis that looks for associative factors in larger areas that constitute trip attractors and generators for child pedestrian travel, as opposed to a microscopic analysis that would look at individual accident sites for direct causative factors. It can therefore be helpful as an indicative tool.

REFERENCES

Ben-Akiva, B. M. E. and Bowman, J. L. (1995) Activity-based modelling system for travel demand forecasting, US Department of Transportation and US Environmental Protection Agency, Washington, D.C. http://tmip.fhwa.dot.gov/clearinghouse/docs/abtf/bowman.pdf

Badruddin A. and Herrington, L. (2006) Solving problems with spatial modelling in GIS, Institute for the Application of Geospatial Technology, Cayuga Community College, Auburn, NY A. http://www.css.cornell.edu/courses/420/lecture15.ppt

Chong, H. Y. (1997) Illustrating degrees of freedom in terms of sample size and dimensionality, http://www.creative-wisdom.com/computer/sas/df.html

Christie, N. (1995) The high-risk child pedestrian: socio-economic and environmental factors in their accidents. **TRL Research Report,** PR117.

Department for Transport (DfT) (2000) Tomorrow's roads - safer for everyone. http://www.dft.gov.uk/stellent/groups/dft_rdsafety/documents/pdf/dft_rdsafety_pdf_504644.pd

f
Department for Transport (2002) Child road safety: achieving the 2010 target, **An action plan prepared in consultation with the Child Road Safety Sub-group of the Road Safety Advisory Panel.**
http://www.dft.gov.uk/stellent/groups/dft_rdsafety/documents/page/dft_rdsafety_507867.pdf
Department for Transport (DfT) (2003) Road safety in primary schools. http://www.dft.gov.uk/stellent/groups/dft_rdsafety/documents/page /dft_rdsafety_504524.pdf
Department of Transport (DfT) (2005) Child pedestrian exposure and accidents. http://www.dft.gov.uk/stellent/groups/dft_rdsafety/documents/page /dft_rdsafety_609992.pdf
Department of Environment, Transport and the Regions (2000). Tomorrows roads safer for everyone.
http://www.dft.gov.uk/stellent/groups/dft_rdsafety/documents/pdf/dft_rdsafety_pdf_504644.pdf
Famoye, F., Wulu, J. T. and Singh, K. P. (2004) On the Generalized Poisson Regression Model with an Application to Accident Data. **Journal of Data Science, Vol. 2**, 287-295
Lawson, S. D. (1990) Accidents to young Pedestrians: distributions, circumstances and scope for countermeasures. Basingstoke: AA Foundation for Road Safety Research.
Lupton, K., Wing, M. and Wright, C. (1999) Conceptual data structures and the statistical modelling of road accidents, mathematics in transport planning and control, 267-276. Proceedings the 3rd IMA international conference on mathematics in transport and planning control, Oxford, Elsevier Science.
Mountain, L, Maher, M and Fawaz, B, (1997), The effects of trend over time on accident model predictions, Proceedings of Seminar K, Traffic Management and Road Safety, European Transport Forum, 145-155.
Mueller, B. A., Rivara, F. P., Lii S. M. and Weiss, N. S. (1990) Environmental factors and the Risk for Childhood Pedestrian-Motor Vehicle Collision Occurrence. **American Journal of Epidemiology, Vol. 132, No. 3**, 550-560
Petch, R.O., Henson, R.R. (2000) Child road safety in the urban environment. **Journal of Transport Geography, Vol. 8**, 197-211.
Pitt, R., Guyer, B., Hsieh, C. and Malek, M. (1990) The severity of pedestrian injuries in children: an analysis of the pedestrian injury causation study. **Accident Analysis and Prevention, Vol. 22, No. 6**, 549-559.
Roberts, I. G., Keall, M. D. and Frith, W. J. (1994) Pedestrian exposure and the risk of injury. **Journal of Paediatric Child Health. Vol. 30, No. 3,** 220-3
Shankar, V, Milton, J and Mannering, F. (1997) Modelling accident frequencies as zero altered probability processes: An Empirical Inquiry, **Accident Analysis and Prevention**, **Vol. 29, No. 6**, 829 – 837.
Sideris, A. L. and Liggett, R. (2005) Death on the crosswalk: a study of pedestrian accidents in Los Angeles. http://www.uctc.net/papers/final%20reports/year16/
Simon, S. (2006) Poisson regression model. Children's Mercy Hospital, http://www.childrens-mercy.org/stats/model/poisson.asp
Tortosa D. (2000) Department of Natural and Health Sciences Lake Superior State University Sault Ste. Marie, Michigan, http://hosting.soonet.ca/eliris/gpsgis/gpsgis.html
Wedagama, D. M. P. (2006a) **The relationship between urban land use and non motorised transport accidents and casualties**, PhD Thesis, Newcastle University.
Wedagama, D. M. P., Bird, R. N. and Metcalfe, A.V. (2006b), The influence of urban land-use on non-motorised transport casualties, **Accident Analysis and Prevention, 38**, 1049-1057.