Modelling the effects of land use and temporal factors on child pedestrian casualties

Dilum Dissanayake \(^a\),*, James Aryaija \(^b\), 1, D.M. Priyantha Wedagama \(^c\), 2

\(^a\) Transport Operations Research Group, Cassie Building, School of Civil Engineering & Geosciences, Newcastle University, Newcastle, NE1 7RU, UK
\(^b\) Atkins Transport Planning & Management, 26th Floor Euston Tower, 286 Euston Road, London, NW1 3AT, UK
\(^c\) Department of Civil Engineering, Faculty of Engineering, Udayana University, Bukit Jimbaran, Bali 80361, Indonesia

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ABSTRACT

This study investigates the suitability of land use variables in predicting the number of child pedestrian casualties; a subject of concern in Great Britain despite sustained improvements in road safety over the past decade. The relationship between land use and transport is used to establish a link between land use and child pedestrian travel; trip attractors and generators are considered as variables that lead child pedestrians to exposure to high risk environments. Casualty records for Newcastle upon Tyne are analysed to reveal trends of temporal variation of child pedestrian casualty numbers. Land use data is combined with the casualty data using GIS techniques to generate relevant inputs for the analysis. Six Generalized Linear Models (GLMs) are developed to analyse the association of child pedestrian casualty numbers and trip attractor land use types. Two are the main models; the first investigates all types of casualty data including slight, serious and fatal events and the second uses only KSI (Killed or Seriously Injured) data in the analysis. The other four models are developed to investigate the temporal variation of child pedestrian KSI and slight casualties over the day (school time and non-school time) and week (weekday and weekend). The results show that secondary retail and high density residential land use types are associated with all child pedestrian casualties. In addition, educational sites, junction density, primary retail and low density residential land use types are also associated with child casualties at different time periods of the day and week. The study findings are found to concur with the current child road safety policies in Great Britain and will, in fact, provide some guidance for local authorities to deliver successful child road safety audits.

1. Introduction

The number of child pedestrians killed or seriously injured (KSI) in Great Britain has been a significant problem over the years. During 2000–2005, of the total child road-based KSI in Britain, 61% was made up of child pedestrian KSI (DfT, 2007). According to the road safety statistics published by DfT (2008a), there has been a considerable reduction in child pedestrian KSI during the past few years (Fig. 1). However the number of casualties recorded, for instance 57 deaths and 1899 KSI in 2007, remains a major concern within the road safety agenda in Britain (DfT, 2008b).

As shown in Fig. 2, it is clear that the number of casualties increases steadily with increasing age. For example, in 2001, the age group 11–15 had an annual KSI rate over four times that of the 0–5 age group and over three times the casualty rate for slight casualties. Over the period of 2001–2005, there has been a decline in KSI and slight casualties for all ages.

In 2000, the British Government launched its strategy for road safety improvement; one of the highlights of which was setting casualty reduction targets based on casualty numbers during 1994–1999 (DfT, 2000). The target that set by the DfT (2000) was to reduce traffic related child deaths and serious injuries by 50% by 2010.

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A study carried out in France, Great Britain and The Netherlands found that children in Britain spent more time near or crossing wider roads or roads with high flows of traffic and were more likely to use unmarked crossings and less likely to be accompanied by an adult (DfT, 2006). Britain has the 10th highest child pedestrian fatality rate out of 37 OECD member states (DfT, 2005).

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 casualties compared to motorised users. One of the most vulnerable non-motorised traffic groups is children. Therefore, this study focuses on child pedestrian casualties. Land use as a principal determinant of trips is one of the main influencing factors for road-based environments and its related variables which include 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 the generation and attraction of traffic. They also stated that land use influences the level of traffic flow, speed and safety. In general, different land use patterns generate or attract different numbers of trips. A rising number of trips increases the probability of casualty occurrences. Therefore, it is reasonable to make an assumption that different land use patterns may generate different casualty rates.

The prime objective of this study is to investigate child pedestrian casualties and their relationship with land use and is expected to be a positive contribution to current safety practices in Great Britain. More explicitly, this study intends to discern the patterns of land use that are highly associated with child pedestrian casualties. The UK Road Safety Strategy (DfT, 2000, 2007) requires local authorities to perform periodical measures to identify the key areas to focus the audits; the proposed methodology provides a starting point by identifying areas that are likely to be associated with child pedestrian casualties.

The methodology was developed by the following steps in this study:

- Preliminary analysis of the child pedestrian casualty data to extract information, mainly on the time of the casualty, severity and location.
- Utilisation of GIS techniques to integrate child pedestrian casualties and urban land use types and administrative boundaries (wards) and to generate necessary data inputs for the analysis.
- Application of Generalized Linear Modelling techniques to investigate all kinds of child pedestrian casualty data, for instance slight, serious and fatal events, that exist within defined administrative boundaries having urban land use types as predictor variables.
- Application of Generalized Linear Modelling techniques to analyse KSI data that exist within defined administrative boundaries considering urban land use types as predictor variables.
- Development of sub-models to investigate the temporal effects on child pedestrian KSI and slight casualties considering urban land use types as predictor variables.
- Investigation of the possible contribution of the findings into current road safety policies in the UK.

The city of Newcastle upon Tyne, the major city in the northeast of England, is chosen as the case study area. The Generalized Linear Modelling techniques have been explicitly incorporated to develop models in reference to child pedestrian casualty data from Newcastle with special consideration of urban land use patterns and their impact on child casualties, in order to investigate a possible relationship between them.

2. The effect of socio-economic, environmental and land use factors on child pedestrian casualties

The child casualty studies carried out in the past primarily looked at its relationship with the physical and social environment. This review basically summarises the work that has been conducted so far, emphasising the impacts of spatial interaction, road environment, socio-economic factors and temporal characteristics on child pedestrian casualties.

Sideris and Liggett (2005) reported that the spatial distribution of child casualties is always uneven. They found that educational, residential and commercial land use types, as well as road and population densities can be used to predict pedestrian casualty numbers. Joly et al. (1991) analysed the effects of geographic and socio-ecologic variations on child casualties in Montreal city and found that zones with high incidence of pedestrian and cyclist

![Fig. 1. Comparison of child accident severities in Great Britain (Produced using the data from DfT, 2008a).](image1)

![Fig. 2. Child accident severity by age in Great Britain (produced using the data from DfT, 2007).](image2)
Casualties have similar characteristics. A recent study by Petch and Henson (2000) indicates that the distribution of child pedestrian or cyclist casualties could not be simply explained by analysis at a district level. Although this analysis did not directly relate to land use, it provides an important indication that the administrative boundary or unit for such an analysis should be smaller than the district level.

Wedagama (2006) investigated the relationship between pedestrian casualties and certain land use types, for example retail, offices, leisure and junction density, on weekdays and weekends. Furthermore, the analysis intended to derive a relationship between different land use types or trip attractors and temporal variation of pedestrian and cyclist casualties. However, the analysis by Wedagama (2006) did not disaggregate the pedestrians by age. Graham et al. (2005) investigated the influence of area deprivation on child and adult pedestrian casualties considering England as a case study. This study concludes that the residential areas are likely to be safer for children than mixed use areas in inner cities.

Over the years, there has been considerable effort to distinguish the locations with high rates of child pedestrian casualties. A number of authors have reported that the areas of high child casualty rates are in the immediate vicinity of residential neighbourhoods and they are highly dependent on road type (Agran et al., 1996; DfT, 2003, 2006; Lawson, 1990). There is a higher contribution to pedestrian casualties from terraced houses, houses in areas with much on-street parking and houses having no play areas with on-street front access (Petch and Henson, 2000). The road environment was also found to be a cause of many pedestrian casualties. Lawson (1990) mentioned that many casualties to young pedestrians occurred on minor roads in small urban areas. Researchers recognised the increased risks posed by through-roads to child pedestrians (Christie, 1995; Roberts et al., 1994). A study by the DfT (2005) titled “Casualty Variation in Britain and Europe” further reinforces this notion.

Some studies found that traffic calming systems are worthwhile for areas with high incidence of child pedestrian casualties. Jones et al. (2005) in a study of two cities in the UK found that traffic calming can reduce the rate of child pedestrian casualties. According to Agran et al. (1996), there is a high risk of child pedestrian casualties in residential streets with many parked vehicles and residences with many families and no enclosures. To reduce pedestrian casualties, they recommended traffic calming systems to reduce speed for areas with high incidence of child pedestrian casualties. Many researchers considered Poisson models to analyse casualty data. However, the assumptions of equal mean and 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. In such cases, the Negative Binomial Distribution is used as a generalization of the Poisson distribution as it does not assume equal chance or randomness for all elements in a distribution (Simon, 2006).

The Generalized Linear Modelling techniques have been used to analyse casualty data in recent years (Sideris and Liggett, 2005; Wedagama, 2006; Famoye et al., 2004). The Generalized Linear Model can be used to confront linear and non-linear effects of continuous and categorical predictor variables on a discrete or continuous dependent variable. The Generalized Poisson model is suggested as more appropriate than the conventional Poisson model due to its capacity to deal with over-dispersion (Yang et al., 2007).

### 4. Case study area

This study investigates data from Newcastle upon Tyne; the regional capital of the northeast of England. Newcastle district belongs to the Tyne and Wear conurbation, which comprises of Newcastle, Gateshead, North Tyneside, South Tyneside and Sunderland. Like most UK cities, Newcastle experiences significant localised congestion at key locations in its central business district. Thus one of the challenges would be to reduce the level of traffic congestion. Car ownership in Newcastle and the northeast region has remained lower than the national average. Hence, the potential for future car ownership growth in Newcastle is high. Indeed it is now increasing at a rate twice the national average.

The city covers an area of 113 km², 2001 Census Data show 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. Newcastle district consists of 26 wards among which 11 wards are within the Newcastle urban periphery (Fig. 3). 10 out of 11 wards in the Newcastle district were incorporated in the analysis. The Heaton ward is not included in the analysis due to land use data limitations. The most and the least populated are the Dene and the West City wards with 6% and 2.4% of the total population. Newcastle Local Authority has a total of 99 schools that are attended by 37 000 pupils.

![Case study area—the city of Newcastle upon Tyne.](image-url)
The child casualty data in this study is obtained as secondary geo-referenced data from the Tyne and Wear Traffic Accident and Data Unit (TADU) based at Gateshead Metropolitan Borough Council. The data consists of the details of child casualties occurring between 2000 and 2005 and was collected for the area between the Ordnance Survey coordinates of 421 500, 563 000 (Eastings, Northings) and 428 000, 569 000 (Eastings Northings) for the top left and bottom right hand corners respectively. The UK regional casualty data is collected from Transport Statistics Great Britain (TSGB, 2008).

Land use data is obtained in secondary form from the School of Civil Engineering and Geosciences at University of Newcastle, Newcastle City Council and EDINA Digimap of Edinburgh University. The land use database consists of the details of the land use classification for Newcastle city as defined by the Office of the Deputy Prime Minister (ODPM), now renamed the Department for Communities and Local Government (DCLG).

5.1 Database statistics

In Newcastle district, the average annual number of casualties and KSI for the period 2000–2005 is 87 and 15, respectively (Fig. 4). The majority of the casualties fall into the slight category.

Fig. 5 shows the distribution of casualties in Newcastle. They are highest in the West City ward (9%) and least in the Jesmond ward (1%). The preliminary spatial analysis with ESRI’s Arc Toolbox reveals that some spatial clusters in the area, for example in and around the city centre, have a relatively higher concentration of retail, leisure and residential land use as well as roads. It should also be noted that two-thirds (66%) of the casualties occurred whilst the children crossed at points more than 50 m away from a designated pedestrian crossing. A significantly high number (10%) occurred on the pedestrian crossings.

5.2 Database preparation for the analysis

At first, a spatial analysis was conducted by using GIS techniques to integrate land use data and casualty data with the target of generating necessary data inputs for the models. The data for the spatial analysis consists of geo-referenced child pedestrian casualties, Newcastle district baseline map with defined ward boundaries, land use classification of Newcastle district and child pedestrian casualties in specific land use and ward.

The outputs of the spatial analysis represent the proportion of independent variables (land use types) and casualties per spatial unit (ward). Fig. 6 shows the flowchart for the data preparation process.

6. Modelling child pedestrian casualties

The Generalized Linear Model (GLM) was selected in this study due to its applicability to 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 order to estimate the GLM, the values of the parameters are obtained by maximum likelihood estimation. Basically, the GLMs are developed in order to predict child pedestrian casualties that can be expected to occur for a given proportion of the type of land use. In order to obtain a valid model, a number of criteria have to be met, so that it can be considered for use in real world application, for instance logical output with appropriate consistency and robustness. Negative Binomial Regression models (NB GLMs) are used when the result for the Poisson GLM shows over-dispersion. Fig. 7 represents the modelling process used in this study.

6.1 Variable selection for the models

Pearson coefficient of correlation is calculated for the selected land use types as shown in Table 1 to check for multi-collinearity. Land use variables including industrial and storage (is), offices (j), vacant land (v), footpaths (w), offices and government buildings (b) and transport (t) are omitted from the modelling process as they do not attract or generate child travel while others including road length (rl), junction density (jd), educational sites (es), primary and secondary retail (pk, sk) and high and low density residential (hd, ld) are selected as trip attractors for child pedestrian travel hence are used as predictor variables. The variables for community buildings (c) and open spaces (o) are not considered in the analysis to allow sufficient degree of freedom in the model estimation.

6.2 Model development and estimation

The models are developed by using the Generalized Linear techniques considering the casualty types and land use types in Newcastle city for the period of 2000–2005 (refer eqn. (1)).

To remove the appearance of ‘at risk’ wards due to road length, it was offset such that the road length variable (rl) enters on the right-hand side of the eqn. (1), but with a parameter estimate constrained to 1.

\[
\ln(\mu) = \ln(rl) + \beta_0 + \sum_{j=1}^{p} \beta_j X_j
\]  
(1)

It implies,

\[
\ln \left( \frac{\mu}{\lambda} \right) = \beta_0 + \sum_{j=1}^{p} \beta_j X_j
\]  
(2)

Where, \( \mu \): the expected value of the dependent variable (i.e. child pedestrian casualties); \( X \): explanatory variables (road length, junction density, land use type); \( \beta_0, \beta_j \): unknown parameters.

Therefore, the GLM can be written as:

\[
\ln(\mu) = \ln(rl) + \beta_0 + \beta_1 jd + \beta_2 es + \beta_3 hd + \beta_4 ld + \beta_5 pk + \beta_6 sk
\]  
(3)

Table 2 represents the number of child pedestrian casualties and the proportions of the land use types for each ward. The casu-
Fig. 5. Child pedestrian casualty distribution in Newcastle city during 2000–2005.

Fig. 6. Flowchart for the data preparation process.

Fig. 7. Flowchart for the modelling process.
Correlation of essential land use variables.

<table>
<thead>
<tr>
<th>CpoD</th>
<th>c</th>
<th>es</th>
<th>hd</th>
<th>ld</th>
<th>o</th>
<th>pk</th>
<th>sk</th>
<th>jd</th>
<th>ln(rl)</th>
</tr>
</thead>
<tbody>
<tr>
<td>CpoD</td>
<td>1</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>1</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0.057</td>
</tr>
<tr>
<td>c</td>
<td>0.75</td>
<td>1</td>
<td>0.25</td>
<td>1</td>
<td>0.42</td>
<td>0.16</td>
<td>0.31</td>
<td>0.40</td>
<td>0.08</td>
</tr>
<tr>
<td>es</td>
<td>0.14</td>
<td>0.25</td>
<td>1</td>
<td>0.24</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>0.055</td>
<td>0.28</td>
</tr>
<tr>
<td>hd</td>
<td>0.40</td>
<td>0.05</td>
<td>0.48</td>
<td>0.24</td>
<td>0.39</td>
<td>0.02</td>
<td>0.07</td>
<td>0.06</td>
<td>0.16</td>
</tr>
<tr>
<td>ld</td>
<td>0.74</td>
<td>0.41</td>
<td>0.48</td>
<td>0.62</td>
<td>0.07</td>
<td>0.32</td>
<td>0.22</td>
<td>0.08</td>
<td>0.23</td>
</tr>
<tr>
<td>o</td>
<td>0.08</td>
<td>0.00</td>
<td>0.12</td>
<td>0.33</td>
<td>0.16</td>
<td>0.34</td>
<td>0.38</td>
<td>0.02</td>
<td>0.11</td>
</tr>
<tr>
<td>pk</td>
<td>0.08</td>
<td>0.26</td>
<td>0.31</td>
<td>0.06</td>
<td>0.44</td>
<td>0.34</td>
<td>0.13</td>
<td>0.15</td>
<td>0.05</td>
</tr>
<tr>
<td>sk</td>
<td>0.74</td>
<td>0.41</td>
<td>0.48</td>
<td>0.62</td>
<td>0.07</td>
<td>0.32</td>
<td>0.22</td>
<td>0.08</td>
<td>0.23</td>
</tr>
<tr>
<td>jd</td>
<td>0.08</td>
<td>0.26</td>
<td>0.31</td>
<td>0.06</td>
<td>0.44</td>
<td>0.34</td>
<td>0.13</td>
<td>0.15</td>
<td>0.05</td>
</tr>
<tr>
<td>ln(rl)</td>
<td>-0.43</td>
<td>-0.08</td>
<td>0.12</td>
<td>-0.23</td>
<td>-0.33</td>
<td>-0.16</td>
<td>0.34</td>
<td>-0.38</td>
<td>-0.02</td>
</tr>
</tbody>
</table>

Correlation of essential land use variables.

For the ALL model, the dispersion parameter is estimated as 0.14 (Table 4) and it is not significant at 95% level. Therefore it is reasonable to presume that the over-dispersion of data is not a matter of concern in this study.

7.1. Effect of secondary and primary retail land use

All models predict that secondary retail (sk) is positively associated with child casualties. This supports the findings by Graham et al. (2005).

Secondary retail shops and stores in the UK are generally located along through-roads and therefore child road safety issue is deemed to be an issue. Secondary retail streets only providing on-street parking will pose 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 (pk) would also have a significant positive association with child casualties, but all models except WE-SLT explain this differently. The insignificance of primary retail parameters in the models may be a result of few observations; only 3 of the 10 wards have a primary retail land use type. On the other hand, most of the primary retail land uses in Newcastle have been pedestrianised for over 10 years so that the chances of experiencing casualty events in primary retail areas are low.

7.2. Effect of high density and low density residential land use

According to the results, high density land use (hd) is negatively associated with child pedestrian casualties. It predicts that...

Table 2

<table>
<thead>
<tr>
<th>Ward</th>
<th>ALL</th>
<th>KSI</th>
<th>ST-SLT</th>
<th>ST-KSI</th>
<th>N-ST-SLT</th>
<th>N-ST-KSI</th>
<th>WE-SLT</th>
<th>WE-KSI</th>
<th>Land use proportions (%)</th>
<th>Jd/km</th>
<th>ln(rl)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Byker</td>
<td>13</td>
<td>4</td>
<td>1</td>
<td>0</td>
<td>7</td>
<td>3</td>
<td>1</td>
<td>1</td>
<td>0.057</td>
<td>0.595</td>
<td>2.706</td>
</tr>
<tr>
<td>Dene</td>
<td>24</td>
<td>3</td>
<td>6</td>
<td>1</td>
<td>12</td>
<td>1</td>
<td>3</td>
<td>1</td>
<td>0.123</td>
<td>10.472</td>
<td>2.049</td>
</tr>
<tr>
<td>Elswick</td>
<td>36</td>
<td>8</td>
<td>9</td>
<td>1</td>
<td>15</td>
<td>5</td>
<td>4</td>
<td>2</td>
<td>0.219</td>
<td>4.724</td>
<td>15.920</td>
</tr>
<tr>
<td>Jesmond</td>
<td>6</td>
<td>0</td>
<td>3</td>
<td>0</td>
<td>2</td>
<td>0</td>
<td>1</td>
<td>0</td>
<td>0.000</td>
<td>6.272</td>
<td>19.771</td>
</tr>
<tr>
<td>Kenton</td>
<td>38</td>
<td>3</td>
<td>8</td>
<td>0</td>
<td>15</td>
<td>3</td>
<td>12</td>
<td>0</td>
<td>0.022</td>
<td>9.865</td>
<td>23.333</td>
</tr>
<tr>
<td>Moorfield</td>
<td>23</td>
<td>4</td>
<td>4</td>
<td>0</td>
<td>10</td>
<td>4</td>
<td>5</td>
<td>0</td>
<td>0.060</td>
<td>1.525</td>
<td>3.206</td>
</tr>
<tr>
<td>Sandyford</td>
<td>9</td>
<td>0</td>
<td>3</td>
<td>0</td>
<td>5</td>
<td>0</td>
<td>1</td>
<td>0</td>
<td>0.033</td>
<td>1.973</td>
<td>12.270</td>
</tr>
<tr>
<td>South Gosforth</td>
<td>11</td>
<td>1</td>
<td>0</td>
<td>0</td>
<td>10</td>
<td>1</td>
<td>0</td>
<td>0</td>
<td>0.000</td>
<td>0.525</td>
<td>9.711</td>
</tr>
<tr>
<td>West city</td>
<td>47</td>
<td>7</td>
<td>2</td>
<td>3</td>
<td>25</td>
<td>3</td>
<td>13</td>
<td>1</td>
<td>0.000</td>
<td>2.172</td>
<td>2.240</td>
</tr>
<tr>
<td>Wingrove</td>
<td>28</td>
<td>4</td>
<td>6</td>
<td>1</td>
<td>11</td>
<td>3</td>
<td>7</td>
<td>0</td>
<td>0.082</td>
<td>4.342</td>
<td>9.464</td>
</tr>
</tbody>
</table>

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**Table 3**

Determination of model fit.

<table>
<thead>
<tr>
<th>No.</th>
<th>Casualty model</th>
<th>Model description</th>
<th>Data type</th>
<th>Time period</th>
<th>Explanatory variables</th>
<th>Deviance/Deg of freedom</th>
<th>Test statistic</th>
<th>Best model</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>ALL</td>
<td>All casualties (slight, serious, and fatal)</td>
<td>ALL</td>
<td>All year</td>
<td>es, hd, ld, pk, sk, jd</td>
<td>14.59276</td>
<td>LR test for NB: $\chi^2 = 20.54, p = 0.000$. Significant at $p = 0.05$</td>
<td>Negative binomial</td>
</tr>
<tr>
<td>2</td>
<td>KSI</td>
<td>KSI (serious and fatal)</td>
<td>KSI</td>
<td>All year</td>
<td>es, hd, ld, pk, sk, jd</td>
<td>3.650512</td>
<td>LR test for NB: $\chi^2 = 0.00, p = 0.5$. Not significant at $p = 0.05$</td>
<td>Poisson</td>
</tr>
<tr>
<td>3</td>
<td>ST-SLT</td>
<td>School time casualties (ST)</td>
<td>Slight</td>
<td>0830–1530 Weekdays</td>
<td>es, hd, ld, pk, sk, jd</td>
<td>4.920896</td>
<td>LR test for NB: $\chi^2 = 1.2, p = 0.136$. Not significant at $p = 0.05$</td>
<td>Poisson</td>
</tr>
<tr>
<td>4</td>
<td>N-ST-SLT</td>
<td>Non-school time casualties (N-ST)</td>
<td>Slight</td>
<td>Holidays &amp; 1530–0830 weekdays</td>
<td>es, hd, ld, pk, sk, jd</td>
<td>4.086733</td>
<td>LR test for NB: $\chi^2 = 0.19 p = 0.33$. Not significant at $p = 0.05$</td>
<td>Poisson</td>
</tr>
<tr>
<td>5</td>
<td>N-ST-KSI</td>
<td>-</td>
<td>KSI</td>
<td>Holidays &amp; 1530–0830 weekdays</td>
<td>es, hd, ld, pk, sk, jd</td>
<td>1.15 $\times 10^{-7}$</td>
<td>LR test for NB: $\chi^2 = 2.18, p = 0.070$. Just not significant at $p = 0.05$</td>
<td>Poisson</td>
</tr>
<tr>
<td>6</td>
<td>WE-SLT</td>
<td>Weekend (WE)</td>
<td>Slight</td>
<td>All weekends of the year</td>
<td>hd, ld, pk, sk, jd</td>
<td>4.466034</td>
<td>LR test for NB: $\chi^2 = 2.18, p = 0.070$. Just not significant at $p = 0.05$</td>
<td>Poisson</td>
</tr>
</tbody>
</table>

**Table 4**

Modelling results.

<table>
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<tbody>
<tr>
<td>$I$</td>
<td>−1.50</td>
<td>−1.13</td>
<td>−0.97</td>
<td>−2.92</td>
<td>−3.19</td>
<td>−1.91</td>
<td>−3.23</td>
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<td>−1.84</td>
<td>−1.14</td>
<td>1.11</td>
<td>−0.77</td>
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<td>$es$</td>
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<td>−1.38</td>
<td>0.28</td>
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<td>0.18</td>
<td>1.82</td>
<td>0.08</td>
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<td>0.12</td>
<td>0.77</td>
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<td>$hd$</td>
<td>−0.10</td>
<td>−2.79</td>
<td>−0.24</td>
<td>−2.51</td>
<td>−0.01</td>
<td>−0.37</td>
<td>−0.11</td>
<td>−2.87</td>
<td>−0.22</td>
<td>−2.15</td>
<td>−0.11</td>
<td>−1.80</td>
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<tr>
<td>$ld$</td>
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<td>0.87</td>
<td>−0.06</td>
<td>−1.56</td>
<td>0.01</td>
<td>0.37</td>
<td>0.02</td>
<td>0.95</td>
<td>−0.02</td>
<td>−0.59</td>
<td>0.09</td>
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<td>$pk$</td>
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<td>1.39</td>
<td>−0.01</td>
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<td>0.01</td>
<td>0.20</td>
<td>0.06</td>
<td>1.58</td>
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<td>$sk$</td>
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<td>3.32</td>
<td>1.37</td>
<td>2.50</td>
<td>1.73</td>
<td>3.49</td>
<td>3.12</td>
<td>2.45</td>
<td>1.09</td>
<td>1.98</td>
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<td>$jd$</td>
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<td>0.30</td>
<td>1.17</td>
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Summary statistics

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<th>n</th>
<th>235</th>
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<th>42</th>
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<td>N</td>
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<tr>
<td>df</td>
<td>14.59</td>
<td>3.65</td>
<td>4.92</td>
<td>4.51</td>
<td>4.09</td>
<td>4.47</td>
</tr>
<tr>
<td>Dispersion parameter ($\alpha$)</td>
<td>0.14 (t-stat. = 1.78)</td>
<td>Neg. binomial</td>
<td>Poisson</td>
<td>Poisson</td>
<td>Poisson</td>
<td>Poisson</td>
</tr>
</tbody>
</table>

Notes: Bold figures are significant at: *95% and **90%.
– in Coef. and t-stat. indicates parameter not estimated and t-stat. not calculated respectively.

the provision of high density land use seems to favour child pedestrians. This result is comparable with the findings of the recent research on child pedestrian casualties in England by Graham et al. (2005).

This is observed in the cases of West City, Kenton and Dene wards, which have high casualty numbers and low percentage of high density areas. In contrast, Jesmond ward that has the highest percentage of high density land use has the lowest number of casualties recorded. Most high density residential (hd) areas in Newcastle city have traffic calming systems and this could be the reason for the negative association of high density residential on child casualties. Jones et al. (2005) stated that traffic calming systems would significantly reduce the rate of child pedestrian casualties.

All models except WE-SLT show that low density residential (ld) areas are not significantly associated with child pedestrian casualties. The road layout and road environment features in low density residential (ld) areas could be a possible cause for not having significant outcome. Although this study does not intend to assess the road network structure for each land use type used in the analysis, this could be an additional component for a further study.

**Table 5**

A summary of the results.

<table>
<thead>
<tr>
<th>Accident model</th>
<th>Land use predictor</th>
</tr>
</thead>
<tbody>
<tr>
<td>ALL</td>
<td>High density (–), Secondary Retail (+)</td>
</tr>
<tr>
<td>KSI</td>
<td>Educational sites (+), High density (–), Secondary retail (+)</td>
</tr>
<tr>
<td>ST-SLT</td>
<td>Educational sites (+), Secondary retail (+)</td>
</tr>
<tr>
<td>N-ST-KSI</td>
<td>High density (–), Secondary retail (+)</td>
</tr>
<tr>
<td>N-ST-SLT</td>
<td>High density (–), Low density (+), Primary retail (+), Secondary retail (+), Junction density (–)</td>
</tr>
</tbody>
</table>

Notes: Land use shown in bold format is significant at 95% level of confidence, while the one significant at 90% confidence level has been included as other entries.
7.3. Effect of educational sites

Another land use type that may have a positive significant influence on the overall number of casualties is the educational sites (es). However the only models that have shown a positive association are the KSI and the ST-SLT models. In this study, educational sites include all schools, colleges and universities and libraries. The GIS data used in this study do not provide sufficient detail to identify the educational sites that are most used by children below the age of 16. This therefore might have an effect on the sensitivity of the modelling results.

7.4. Implications from N-ST and ST models and WE models

Previous research found that the child casualties occur largely during either morning or evening peaks (DfT, 2002, 2008b; Sharples et al., 1990). The database used for this study confirms this finding (see Table 2).

N-ST models: It is observed that high density (hd) and secondary retail (sk) land use types are found to have significant association in relation to occurrence of child casualties. The children are likely to visit retail stores after school hours, therefore have more exposure to risk while they cross roads. It would be inappropriate to conclude that they should therefore be prevented from visiting the shops, but rather the traffic environment in such areas could be modified to suit their needs.

ST models: The ST-SLT model clearly explains that educational sites (es) and secondary retail (sk) have a positive relationship with child casualties. Therefore, some measures to safeguard child pedestrians as they travel to and from school are recommended.

WE models: The WE-SLT model indicates that low and high density residential (hd, ld), primary and secondary retail (pk, sk) as well as junction density (jd) have a significant association with child casualties. It is important to note that a high junction density has a negative association with weekend casualty events. The preliminary analysis of the casualty data shows that most accidents occurred away from pedestrian crossings. Increased junction density therefore appears to reduce the number of casualties as it is assumed that where there are more junctions there will be more pedestrian crossings permitting safe crossing for child pedestrians.

7.5. Contributions from this research to the current road safety policies in the UK

Current road safety policies in Great Britain, namely the Road Safety Strategy (DfT, 2000, 2007) and the Action Plan Report of the Road Safety Advisory Panel (DfT, 2002), require 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 with regard to a reduction in the severity and the number of casualties. It also empowers them to implement the speed limits, to introduce traffic calming measures and pedestrian crossings and to develop and implement school travel plans (DfT, 2000). Unfortunately local authorities are finding such needs hard to put into practice. It is found that the models could assist in carrying out child road safety audits as the proposed methodology provides a starting point by identifying areas that are likely to be associated with high incidences of child pedestrian casualties. The local authorities may then focus on these areas and carry out detailed investigations.

8. Conclusions

This study investigates the relationship between child pedestrian casualties and urban land use considering Newcastle upon Tyne as a case study. The GIS technique is used to analyse the occurrence of child pedestrian casualties at the ward administrative level.

Six GLMs are developed to investigate the relationship that exists between child pedestrian casualties and land use with emphasis on various trip attractors and generators relevant to child travel. The results show that secondary retail and high density residential are the main land use types associated with child pedestrian casualties; the former is positively associated while the latter is negatively associated. It also found that low density residential, educational sites and primary retail are also positively associated while junction density is negatively associated with child pedestrian casualties.

The UK Road Safety Strategy recognises the importance of child road safety research and its contributions to the development of casualty reduction initiatives. The findings of the study concur with the needs addressed in the Road Safety Strategy (DfT, 2000, 2007) and Road Safety Advisory Panel Action Plan on Child Road Safety (DfT, 2002).

Nevertheless the study finds that the association of child pedestrian casualties to land use can reveal important linkages where underlying characteristics are likely to be causative factors of such casualties. It performs a mesoscopic level casualty 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 casualty events for direct causative factors. It can therefore be helpful as an indicative tool but not as a deterministic one.

Acknowledgments

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References


