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Development of an adjusted scan statistic for the efficient detection of road collision 'hot spots' along the road network in Ireland

A thesis submitted to the
University of Dublin, Trinity College
for degree of
Doctor of Philosophy

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Department of Public Health & Primary Care
March 2012

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Summary

Road traffic collisions impose a major burden on society, thus there is a real incentive for inter-sectoral collaboration when decisions and policies are being formulated. This research is set in the context of the latest 5-year road safety strategy (2007 - 2011) which was developed to help reduce road fatalities and serious injuries in Ireland.

The main aims of this research are to develop the required efficient statistical methodology for identifying road traffic collision hot spots/corridors along the road network in Ireland and to assess the human, environmental and infrastructural factors associated with fatal/serious road traffic collision injuries associated with single vehicle and multi-vehicle collisions. The specific objectives of this thesis were: to test utility of known methods and identify limitations, develop approach to overcome limitations while maintaining strengths of existing methods, identify road collision hot spots and corridors on each individual national primary and national secondary road and the creation of geographical maps to illustrate all identified collision hot spots/corridors for each national road. Additionally the development of global models were required to examine the human, environmental and infrastructural factors associated with fatal/serious single vehicle and multi-vehicle collision injuries in the Republic of Ireland.

Temporal fixed window scan statistics and spatio-temporal scan statistics were applied to fatal/serious road traffic collisions in the Republic of Ireland (Naus's scan statistic) and to all road traffic collisions in cities: Dublin, Cork, Limerick, Galway and Waterford (Bernoulli scan and Space-time permutation scan). Adopting the variable window scan statistic to road traffic collisions required the adaptation of Nagarwalla's scan statistic to distance along a (linear) road as distinct to distance in (linear) time. Nagarwalla's variable window scan statistic was applied to all road traffic collisions occurring on individual national roads. In this study, a systematic approach was developed to extract multiple significant hot spots/corridors occurring on each of these individual national primary and national secondary roads. Semantic segmentation was adopted in the identification of collision hot spots/corridors occurring on Irish national secondary roads as these road often had continuity broken by other roads, thus providing natural semantic segments. Additionally road collision hot spots/corridors were identified for two intersecting road regional roads and a national secondary road broken into segments based on designated speed limits.

Findings in this study illustrated the applicability of variable window scan statistics to identify road traffic collision hot spots/corridors. Interesting results indicated the

necessity to examine the underlying distribution of road traffic collisions. If the underlying distribution of collisions on a particular road (or section of road) is uniform then scan statistics will not identify a collision hot spot/corridor even though these collisions may actually be a collision hot spot/corridor. Comparison of road collision hot spots/corridors (identified via scan statistics) to designated speed collision prone zones (identified by An Garde Síochána) indicates that scan statistics are sometimes more sensitive to the detection of collision hot spots/corridors than the Garda detected speed collision prone zone, as for example scan statistics identify collision hot spots/corridors with shorter spanning distances (in length).

A Full Bayesian framework was used to estimate logistic regression models for fatal/serious 'driver only' single vehicle collision injuries. Two binomial regression models were also estimated for fatally/seriously injured persons as a proportion of the total number of persons involved in 'driver with passengers' single vehicle collisions and persons involved in multi-vehicle collisions. Statistically significant explanatory variables for single vehicle 'driver only' collisions included driver sex, light, public/bank holiday weekend, speed limit, road surface, road geometry, vehicle type and collision type. In comparison, statistically significant explanatory variables for single vehicle 'driver with passengers' collisions included driver age, driver sex, light, road surface, road geometry, vehicle type, junction and collision type. Unfortunately, due to data limitations driver age and driver sex was not available for the multi-vehicle collision injury model, however statistically significant explanatory variables include light, weekend, road type, road surface, speed limit, road geometry, junction and collision type

Model results indicated that single vehicle 'driver only' (O.R. 0.61; 95%C.I. (0.49,0.77)), 'driver with passengers' (O.R. 0.53; 95%C.I. (0.43,0.64)) and multi-vehicle (O.R. 0.71; 95%C.I. (0.63,0.80)) collisions occurring during the hours of darkness were less likely to contain a fatal/serious injury than collisions occurring during daylight. Single vehicle 'driver only' (O.R. 0.80; 95%C.I.(0.65,0.98)),'driver with passengers'(O.R. 0.79; 95%C.I.(0.66,0.94))) and multi-vehicle (O.R. 0.81; 95%C.I.(0.74,0.89)) collisions occurring on a wet road surface were also less likely to result in a fatal/serious injury. Single vehicle 'driver only' (O.R. 1.37; 95%C.I.(1.02,1.85)) and multi-vehicle (O.R. 1.29; 95%C.I.(1.13,1.47)) collisions occurring on a hill/gradient were more likely to contain a fatal/serious injury than collisions occurring on a straight section of road, however, in contrast, single vehicle 'driver with passengers' (O.R. 0.68; 95%C.I.(0.49,0.93)) collisions occurring on a hill/gradient were less likely to contain a fatal/serious injury. Multi-vehicle (O.R. 0.63; 95%C.I.(0.56,0.71)) and single vehicle 'driver with passengers' (O.R. 0.74; 95%C.I.(0.56,0.98)) collisions occurring at a junction were less likely to contain a fatal/serious injury and collisions occurring on roads with a speed limit greater than

50km/h were more likely to contain a fatal/serious injury. Male drivers involved in a single vehicle 'driver only' (O.R. 1.49; 95%C.I.(1.18,1.89)) and 'driver with passengers'(O.R. 1.56; 95%C.I.(1.26,1.93)) collision were more likely to sustain a fatal/serious injury than female drivers. Multi-vehicle (O.R. 1.44; 95%C.I.(1.12,1.84))and single vehicle 'driver-only' (O.R. 1.65; 95%C.I.(1.10,2.49)) collisions occurring on a public/bank holiday weekend were more likely to contain a fatal/serious injury than collisions occurring on a week day.

Findings in this study highlight the importance of examining global model results in addition to focused scan results, as conditions affecting different road traffic collisions are not necessarily indicative of collisions occurring at road collision hot spots/corridors. Collaboration and relaying findings from this study to key stakeholders will be fundamental to ensuring that all research is brought to the attention of those charged with addressing the unacceptable level of road fatalities and injuries.

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Chapter 1

Introduction

Road traffic collisions impose a major burden on society. Approximately 40,000 people are killed per annum in Europe and many more are injured as a result of collisions [1]. A mid-term review published by the European Transport Safety Council (ETSC) reports that road transport is the leading cause of fatalities for E.U. citizens under the age of 45 years, with approximately 115 persons being killed each day [2].

In 2001 the E.U. set itself a target to reduce the yearly number of road deaths by 50% over the period 2001 to 2010. In numerical terms this equated to 54,300 fatalities in 2001 to about 27,100 fatalities in 2010 [3]. This ambitious target was not reached by the 2010 deadline, and approximately 34,900 people lost their lives in road collisions in 2009 [4]. Between 2001-2009 Latvia, Spain, Portugal and Estonia all achieved at least 50% reduction in road fatalities, with France and Lithuania closely set to follow [5]. The Republic of Ireland is currently implementing the third road safety strategy (2007–2011), which has the objective of "radically and sustainably improving safety on Irish roads" [6]. In June 2010, Ireland was awarded a Road Safety Award from the European Transport Safety Council for achieving a 41% reduction in road fatalities since 2001. Currently Ireland is ranked 7th out of the 27 EU member states in road fatalities per million population [7].

Research indicates that road traffic collisions are a leading cause of unintentional serious injuries fatalities in the Republic of Ireland [8]. Over a fourteen year period (1996–2009) 4,788 fatal, 92,866 injury and 300,303 material damage collisions were recorded in the Republic of Ireland. Some 5,323 persons have been killed and 144,346 persons have been injured as a result of these collisions [9, 10]. Boland et. al. [11] found that mortality rate from motor vehicle traffic collisions and the admission for some injuries into hospital were higher for rural residents than urban residents. Possible reasons for this excess were given as a combination of speed, drink-driving, poor-lighting and narrow roads. The estimated cost of road traffic collisions for one year was 1.38 billion Euro [9], thus there

is a real incentive for intersectoral co-operation when transport decisions and policies are being formulated [12].

Several policies and interventions, which target a diverse range of areas relating to road safety have been introduced in the Republic of Ireland to help reduce the number of fatal and serious road traffic collisions. Section 2.1 outlines many of the legislative reforms and safety promotions that have been implemented in Ireland since the late 1990s. While it is expected that many of the policies and road safety initiatives already undertaken and those being proposed will have some impact on the numbers of road collisions, the focus of this research is on an essential component of any road safety programme, that is, the valid identification of collision 'hot spots' and 'corridors' along the road network.

The Irish road network consists of roads classified as motorway, national primary roads (i.e. major long distance through roads linking the principal ports or airports, cities and large towns), national secondary roads (i.e. medium distance through roads connecting important towns and linking up to the national primary roads), regional roads (i.e. provide the main links between national roads) and local roads (all other urban and rural roads). As the road network in Ireland carries 96% of passenger traffic and 89% of freight traffic, this makes roads the dominant mode of transportation [13]. Identification of hot spots (defined as spanning less than 500m in length) and collision corridors (defined as sections spanning less than 5km in length) are expected to provide highly informative and beneficial information for decision makers and road safety experts.

1.1 Aims and Objectives

This research is set in the context of the latest 5-year road safety strategy (2007 – 2011) which was developed to help reduce of road fatalities and serious injuries in Ireland.

The main aims of this research is to develop the required efficient statistical methodology for identifying road traffic collision hot spots/corridors along the road network in Ireland and to assess the human, environmental and infrastructural factors associated with fatal/serious road traffic collision injuries. Findings from this research will be relayed to key stake-holders - the Road Safety Authority, National Roads Authority and Garda Traffic Bureau.

This research is based on two thematic approaches:

- Scan statistics to identify road collision hot spots/corridors
- Global models for road traffic collisions classified by type

The specific objectives of this thesis are:

- Scan Statistics
  - Test utility of known methods and identify limitations
  - Develop approach to overcome limitations while maintaining strengths of existing methods
  - Apply temporal scan statistics to fatal/serious road traffic collisions in the Republic of Ireland (Naus's scan statistic) and to all road traffic collisions in cities: Dublin, Cork, Limerick, Galway and Waterford (Bernoulli model).
  - Employ space time permutation scan for all (fatal, serious and minor) road traffic collisions in cities: Dublin, Cork, Limerick, Galway and Waterford
  - Adapt and refine variable window scan statistic by calculating distance (km) along a linear network (road) as distinct from distance (days) in (linear) time for road traffic collisions on national roads in the Republic of Ireland
  - Create visual maps illustrating identified collision hot spots/corridors for each individual national road
- Global Models
  - Follow best practice recommendations [14] to develop Bayesian hierarchical models for road traffic collision data. Human, environmental and infrastructural factors associated with fatal/serious single vehicle and multi-vehicle collision injuries in the Republic of Ireland will be examined.

1.2 Thesis Overview

Chapter two gives a reasonably comprehensive review of the very extensive literature pertaining to: road traffic collision hot spots, collision factors, and the effectiveness of policies and measures. Chapters three and four relate to scan statistics. Chapter three introduces the conceptual basis of scan statistics and their applicability to road traffic collision data shall be outlined. Chapter four provides results from the application of scan statistics to road traffic collision data in the Republic of Ireland. Detailed maps will give a visual illustration of these results. Chapter five outlines the statistical methodology adopted in the global models and outlines the results obtained form the examination of explanatory factors associated with fatal/serious injuries ensued by road traffic collisions classified by collision type. Finally, chapter six discusses the results, conclusions from the findings of this study and outlines proposed recommendations and further research.

Chapter 2

Literature Review

This chapter is divided into four thematic sections. Section 2.1 will introduce the various policies/measures, legislative reforms and government bodies established to help reduce road traffic collisions in Ireland. This section demonstrates the united effort from different sectors to help reduce fatal/serious road traffic collisions. Section 2.2 gives details of international and Irish research relating to the effectiveness of road safety interventions. Section 2.3 outlines literature which examines road traffic collision factors, thus providing a meaningful insights into the circumstances surrounding road traffic collisions and section 2.4 outlines the statistical methodologies used in these studies. Finally, section 2.5 examines research pertaining to hot spot identification with specific focus on the application of scan statistics. An overview is provided in section 2.6

2.1 Policies and Measures

Several policies and measures have been implemented in the Republic of Ireland through the Road Safety Strategies (1998–2002; 2004–2006 and 2007–2012). The primary objective of these strategies is the reduction of fatalities and serious injuries which result from road traffic collisions. Specific areas targeted by these strategies include increasing public awareness, education, vehicle safety and law enforcement.

2.1.1 Governing Bodies

On the 1st September 2006, the Road Safety Authority (RSA) was formally established. The RSA takes a lead role in the area of road safety and has an objective to "bring Ireland's road safety record into line with best practice countries throughout the World". It also has "responsibility for the delivery of functions across four critical areas of road safety - Education, Enforcement, Engineering and Evaluation" [15], thus collaborations

exist with An Garda Síochána (Ireland's national police force), education sector, health sector, local authorities, the media and National Roads Authority (NRA). The NRA was formally established on the 1st January 1994, and has "overall responsibility for planning and supervision of construction and maintenance works" [16] on the network of national roads in the Republic of Ireland.

Educational programmes have been introduced in primary and post primary schools to teach children about the importance of road safety. Media campaigns have focused on specific areas such as speeding, drink-driving and seat-belt wearing. Awareness campaigns have focused on the use of reflective clothing/markings by pedestrians when walking in the hours of darkness and driver awareness of other road users such as cyclists, motorcyclists and pedestrians.

2.1.2 Speed Limits

The Irish road network consists of roads classified as motorway, national primary roads, national secondary roads, regional roads and local roads. All Irish public roads have a designated speed limit, and if no speed limit sign is present then the default speed limit applies. A public road, as defined in the Road Traffic Act 1993 is "a road over which a public right of way exists and the responsibility for the maintenance of which lies on a road authority" and a speed limit "establishes the maximum speed at which vehicles are legally permitted to travel on a length of road. It does not indicate the speed at which all vehicles may travel at all times in all conditions" [17]. Details relating to each road type and corresponding speed limit are discussed in section 3.3. With effect from the 20th January 2005, the Road Traffic Act 2004 (No. 44 of 2004) provided a legislative basis for speed limits in Ireland. This Act introduced the default speed limits (which were converted from an imperial system of miles per hour (mph) to a metric speed system of kilometers per hour (km/h)) for roads in built-up areas, on motorways, rural national roads, rural regional roads and local roads. The power given to county and city councils to make special speed limit bye-laws was also enhanced. Section 9 (9) of the Act imposed a requirement that in making bye-laws county and city councils should have regard to the application of special speed limits. On the 15th December 2008, the Minister of State for Transport amended the guidelines for the application of special speed limits. "The Guidelines (April 2005) at section 5.6.2 prohibited the application of a special speed limit of 30km/h on a national road. Section 5.6.2 has been amended to remove this prohibition. The position now is that, subject to obtaining prior written consent from the National Roads Authority, a special speed limit of 30km/h may be applied to a national road in accordance with the Guidelines" [18] Other amendments relate to speed limits at road work and uniform application of appropriate speed limits. On the 31st January 2010,

a controversial bye-law enforced a 30km/h speed limit zones in Dublin city centre. The aim of this lowered speed limit is to improve road safety. This bye-law has been widely criticised - "30km/h limits were designed to be introduced in conjunction with engineering measures and traffic calming so that they are effectively self-policing. In applying it to thoroughfares Dublin City Council is acting beyond the scope envisaged in the Road Traffic Act of 2004 and is presenting an absurd and unnecessary enforcement challenge for Garda which is wasteful of their resources" *. Currently this bye-law is under review.

2.1.3 Vehicle Related Preventative Measures

The National Car Test (NCT) was introduced in the Republic of Ireland on 4th January 2000 as part of an E.U. directive for compulsory car testing in all member states. The NCT is a preventative road safety measure which ensures vehicles are in good working condition. All cars aged 4 years and over must undergo an NCT. Vehicles that pass the test will have to undergo repeat tests every 2 years. Since June 2011, cars over 10 years old have to be tested each year. Failure to comply with the NCT process/display the NCT disc results in fines of up to 1,500 Euro in addition to administration of penalty points (see section 2.1.5 for details relating to the penalty point system). The NCT aims at " improving road safety and enhancing environmental protection" [19].

The National Transport Authority manages the regulation of the Small Public Transport Vehicle sector in Ireland through its Taxi Regulation Directorate. NCT requirements for Taxis differ from private vehicles as Taxis must undergo an NCT every year. "An NCT certificate is not required for a vehicle that is less than three months old and that has travelled less than 3,000 kilometres" [20].

"The Commercial Vehicle Test (CVT) is a preventative road safety measure that ensures all commercial vehicles (i.e. all goods vehicles, all goods trailers with a design gross vehicle weight exceeding 3,500 kgs., buses with more than eight passenger seats, and ambulances) meet a minimum standard in terms of road-worthiness" [21]. Previously commercial vehicles were required to have passed a DOE (Department of Environment) test in order to obtain a CRW (Certificate of Road-worthiness), however the DOE test (which was introduced over 20 years ago) has been replaced with the more up-to-date testing regime of the CVT. All commercial vehicles are required to undertake a CVT test once the vehicle is one year old and every year thereafter.

*http://www.aaireland.ie/publicaffairs/press-centre

2.1.4 Driving License

To improve driver competency, the driving license system has evolved and been updated to comply with "E.U. requirements for harmonising driver licensing and testing" [22]. The driving test was originally introduced in 1964, with the purpose of assessing driver competency. The introduction of the Theory test in the Republic of Ireland in 2001 was to ensure that candidates had to pass a computer based test on general road safety knowledge and motoring legislation before they could obtain a provisional drivers license. A provisional licence is issued to enable a person to learn to drive and to apply for a driving test. Learner Permit Licences were introduced on 30th October 2007 by Statutory Instrument (S.I.) No. 719 of 2007 Road Traffic (Licensing of Learner Drivers) Regulations 2007. The Learner permit license replaced the provisional license. The learner permit holds the same purpose as the provisional license except these permits are subject to a number of conditions. As of 30th June 2008, all drivers possessing a learner permit must be accompanied by a person who has held a full drivers license for a continuous period of two years [15].

2.1.5 Penalty Point System

The penalty point system for driving offences was introduced into legislation in the Republic of Ireland in the Road Traffic Act 2002. The objective of this system was to positively influence and improve driver behaviour, thus reduce the number of fatalities and serious injuries. "A penalty point is essentially a formal reprimand by the Gardaí endorsed on your license that shows you are guilty of a specified driving offence" [19] Additionally, the driver must also pay the corresponding fine associated with the driving offence. Penalty points remain on a license for three years and if a driver obtains 12 penalty points within any 3-year period he/she will be disqualified from driving for 6 months. Prior to 2002, offences, such as speeding were punishable through "on-the-spot fines". A full list of penalty point offences and associated fees are given in Appendix (p. 178).

2.1.6 Alcohol

On the 11th January 2001, a good practice recommendation was issued by the European commission to member states to lower blood alcohol concentration (BAC) levels for driving. In October 2006, the first E.U. alcohol strategy was adopted - this strategy highlighted the need for member states to set and enforce a blood alcohol concentration (BAC) maximum of 50mg/100ml for drivers of motorised vehicles, and set a lower limit for inexperienced and professional drivers. The first progress report based on the

implementation of the E.U. alcohol strategy was issued in 2009 [23], this indicated that Member States had made substantial progress in drink-driving counter-measures since the adoption of the E.U. Alcohol Strategy in 2006 and that almost all Member States now implement national drink-driving campaigns. At the time this progress report was published, only three Member States - namely Ireland, U.K. and Malta, continued to permit a higher BAC than the recommended 50mg/100ml maximum. Approximately half of the 27 Member States had reduced BAC level to 20mg/100ml or zero level for inexperienced drivers or certain groups of professional drivers.

The Health Services Executive* examined alcohol related road traffic collision fatalities for 2003–2005 [24]. This report built on the foundations of an earlier report relating to alcohol and road traffic collisions for 2003 [25]. Findings suggested that during 2003-2005 inclusive, 31% (of 995 fatal collisions on Irish roads) were alcohol related. Due to the fact that approximately one third of the blood alcohol levels were not taken/not available for the analysis, the authors suggested that this percentage may under-estimate of alcohol related collisions and gave recommendations that the BAC should be lowered in Ireland to 50mg/100ml which would bring Ireland in-line with other E.U. member states. At the time this report was written the legal BAC limit in Ireland was 80mg/100ml and random breath testing had not yet been introduced. In July 2006, An Garda Síochána were given permission to perform random breath tests, and in 2009, mandatory breath testing at the scene of an accident was introduced. Subsequently, on the 30th November 2009, a Road Traffic Bill was published which reduced BAC from 80mg/100ml to 20mg/100ml for learner, novice and professional drivers and 50mg/100ml for other drivers. The bill also introduced mandatory testing for drivers involved in collisions and includes provisions to introduce administrative fixed penalties for certain drink driving offences. Currently this bill is being considered by the Irish parliament.

2.1.7 Overview: Policies and Measures

This research is set in the context of the latest 5-year road safety strategy (2007 - 2011) which was developed to help reduce road fatalities and serious injuries in Ireland. Section 2.1 provided descriptions of various policies/measures, legislative reforms and government bodies which have been established in Ireland to help reduce road traffic collisions. Specific areas targeted by these strategies include increasing public awareness, education, vehicle safety and law enforcement. This section demonstrates the united effort from different sectors to help reduce fatal/serious road traffic collisions.

*The Health Service Executive delivers thousands of different health and social services in hospitals and communities in the Republic of Ireland (see http://www.hse.ie)

2.2 Effectiveness of Policies/Measures

It is of great importance that policy-makers know whether the strategies devised to reduce mortality/morbidity and traffic related collisions are effective in achieving this aim [26]. Although the research outlined in this section is not directly applicable to the research undertaken in this study, this literature section contributes to the overview of the wide variety of research that analyses road traffic collisions.

2.2.1 Irish Research

Studies on mortality and morbidity in Ireland have indicated that motor vehicle traffic collisions are the leading cause of unintentional injury fatality [8][11].

Cunningham et.al. [27] examined the effects of age on collision severity in Irish road traffic collision patients admitted into two Irish trauma centres in 1995. Unfortunately, the sample size used in this analysis was very low - of the 525 patient admissions for 1995, only 39 were elderly patients aged 65+yrs, and 38 patients aged 18-64yrs were randomly selected for the comparison. Elderly patients were compared to younger patients and findings from this study suggest that strategies aimed to reduce mortality and morbidity from road traffic collisions involving the elderly, should focus on older pedestrians during daylight hours and safety in public transport. A study by Martin et.al. [28] analysed the pattern of road traffic collisions involving pedestrians. Elderly pedestrians (65+yrs) were compared to younger pedestrians (aged 18-64yrs) over a five year period (1998–2002). Relative risk results reported in this study indicated that road traffic collisions involving elderly pedestrians aged 65+ years occur more frequently during daylight hours and in good weather conditions. The authors suggested that prevention strategies should target the traffic environment and other road users rather than older people.

In the context of strategies implemented in Ireland to reduce road collision fatalities and serious injuries, studies have been conducted to determine the impact of introducing penalty point legislation* on maxillofacial injuries [29], spinal injuries [30][31] and on acute hospital trauma services [32][33]. Chi-square tests were used to used to asses the impact of the introduction of penalty points on road traffic collision spinal related admissions [31] and numbers of maxillofacial injuries [29]. Percentage reduction in the number of admissions were estimated by Lenehan et.al [32]. Findings from these studies have indicated that there has been a reduction in the injuries/hospital activity associated with traffic accidents in the initial six-month period after the introduction of the penalty point legislation but this reduction was not sustained [30][31][33]. In contrast, a reduction

*The penalty point legislation was introduced on 31st October 2002

in maxillofacial injuries continued to be apparent in the second six months after the penalty point legislation was introduced [29].

Unfortunately, research on the impact of the penalty point system does not take specific penalty point offences into consideration, as for example, penalty points for: speeding was introduced in October 2002, driving with no insurance was introduced in April 2003 and penalty points for drivers and children was introduced in August 2003. In Ireland, it is not possible to link hospital admissions data with road traffic collision data that is recorded by the Garda at the scene of a collision, thus circumstances surrounding the collision in the above research studies are based on questionnaires/surveys that were given to the patients that were admitted into hospital.

2.2.2 Speed Related Research

International Research

Keall, Povey and Frith [34] evaluated the first year results of a hidden speed camera trial in 100km/h speed limit areas in New Zealand. An interrupted time series design with a control area was used in this study. Results indicated that hidden speed cameras were associated with significant net reductions in speeds, collisions and casualties both on 100km/h roads generally and on specific speed camera sites. Public attitudes which initially changed in response to the programme were found to largely revert to pre-trial levels. Further study [35] found that analysis of two years data showed that reductions in speeds, collisions and casualties associated with the hidden camera programme were being sustained.

Grundy et.al. [36] examined the effect of a 20mph speed limit in London. Longitudinal changes in road casualties within road sections were analysed using conditional effects Poisson models. Data in this study covered a 20 year period (1986-2006). Findings indicated that these 20mph zones were effective in reducing road casualties and there was no evidence to suggest casualty migration to areas adjacent to these zones. Rock [37] examined the impact of the 65mph speed limit on road traffic collisions on rural interstates in the state of Illinois. Application of ARIMA techniques to model collision data before and after the speed limit was increased from 55mph to 65mph. Findings from this study indicated that the increased speed limit lead to an increase in collisions and corresponding fatal and serious injuries. Lee, Hellinga and Saccomanno [38] examined the safety benefits of variable speed limits. A real-time crash prediction model was developed using a log-linear model. This study simulated traffic conditions on a free-way section in Toronto, Canada. Findings suggested that variable speed limits may reduce potential collisions through reducing speed limit during risky traffic conditions. Wong et.al. [39]

conducted before-after studies to examine the effect of raised speed limits on collision counts for major urban roads in Hong Kong. Speed limits were raised by 10-20 km/h from 50-70 km/h on 19 road sections in Hong Kong. Results showed fatal and serious collisions had increased after the change in speed limit in the majority of treatment sites. A report by Elvis, Christensen and Amundsen [40] conducted a meta-analysis of the literature that examined how changes in speed affected the number of road traffic collisions, the number and severity of injuries to road users. The study evaluated the Power Model of the relationship between speed and road safety. (The Power Model described the relationship between speed and road safety in terms of six equations). Results indicated that a statistical relationship between speed and road safety exists. Aarts and van Schagen [41] reviewed empirical studies which examined the relationship between speed and road traffic collisions. Findings suggested that there is a significant relationship between speed and road traffic collisions and collision severity. Other studies that have examined the effects of specific speed limits on road traffic collisions include research on the 30km/h speed limits within built up areas [42] and residential areas [43]; and 80km/h speed limits on rural roads [44].

Irish Research

The Road Safety Authority (RSA) have conducted a number of surveys to determine the effectiveness of speed enforcement measures, safety initiatives and to inform the on-going review of public policy in relation to road safety [17]. The annual speed survey monitors changes in free speeds of vehicles on urban and rural roads. Free speeds are defined as "speeds at which drivers choose to travel when unconstrained by road geometry (e.g. sharp bends, intersections or hills), weather conditions (e.g. rain) or traffic conditions (e.g. congestion)" [13]. A total of 11,935 cars were surveyed in the 2008 free speed survey - with 37% (4,428) of the cars travelling on urban roads and 63% travelling on rural roads. The main findings from this survey indicated that 22.6% of the cars surveyed on rural roads and 61% of cars on urban roads exceeded the designated speed limit.

2.2.3 Alcohol Related Research

Studies have also been conducted to analyse the effect of alcohol campaigns, drink driving policy, and blood alcohol limits on fatal and serious injury collisions.

International Research

Mann et.al. [45] reviewed evidence introducing/lowering legal alcohol limits for driving. In most, but not all cases where an evaluation was conducted, some jurisdictions sus-

tained reductions in collision rates were reported. However in some cases the effects of introducing/lowering the limit produced relatively small/temporary effects. Nagata et.al. [46] apply time series analysis to examine the effectiveness of a new law that was passed by the Japanese Government in 2002. This law reduced the allowable breath alcohol test from 0.25 to 0.15 mg/l and blood alcohol concentration from 0.05% to 0.03%. In addition monetary fines and penalty points were also given. Results from this study indicated a 38% reduction in the rate of alcohol-related traffic fatalities per billion kilometers in the post law period. Elder et.al. [47] performed a systematic review to determine the effectiveness of random breath testing (RBT) and selective breath testing (SBT) check-points for the Guide to Community Preventive services. None of the literature reviewed directly compared RBT and SBT check-points, however, despite variations in study design and period of observation, results generally indicated substantial reductions were observed for both check-point types.

A review of literature by Elder et.al. [48] examined 13 studies that assessed the effectiveness of school-based programs for reducing drink driving and riding with drink drivers. Three types of interventions were included in this review - instructional programs which were generally conducted in the class room; peer organisation programs, which were conducted in a variety of school and non-school settings and social norming programs, which were conducted on college campus'. A lack of sufficient evidence limited the possibility of determining the effectiveness of these programs for reducing drink driving, however, there was sufficient evidence to suggest that the school-based instructional programs were effective in reducing riding with drink drivers. Several studies have been conducted to determine the effects of alcohol and related topics with road traffic fatalities or serious injuries [49][50][51][52].

Irish Research

As previously mentioned in section 2.1.6, a report by Bedford et al. [24] suggested that during 2003-2005 inclusive, 31% (of 995 fatal collisions on Irish roads) were alcohol related. Due to the fact that approximately one third of the blood alcohol levels were not taken/not available for the analysis, the authors suggested that this percentage may under-estimate of alcohol related collisions and gave recommendations that the BAC should be lowered in Ireland to 50mg/100ml which would bring Ireland in-line with other E.U. member states. At the time this report was written the legal BAC limit in Ireland was 80mg/100ml and random breath testing had not yet been introduced.

2.2.4 Seat Belt Usage Research

International Research

Several studies have determined the effects of seat-belt legislation on fatalities and serious collision related injuries. Houston and Richardson Jr. [53] applied a Box-Tiao intervention analysis of the time series to compare monthly fatalities and injuries from before and after the change of seat-belt law from secondary to primary enforcement in California. Results indicated that the change in enforcement significantly reduced injuries, however there was no statistically significant impact on fatalities. Harvey and Durbin [54] applied an intervention analysis based on structural time series to determine the effects of seat-belt legislation on British road casualties. Analysis indicated a significant net reduction in fatalities and injuries. Carpenter and Stehr [55] used weighted least squares models to focus on youth outcomes and found that mandatory seat-belt laws significantly reduced traffic fatalities (8%) and serious injuries (9%) resulting from fatal collisions for 14-18 year old youths. Data for this study was taken from the national, state, and local Youth Risk Behaviour Surveys (YRBS) from the Centres for Disease Control and from the Fatality Analysis Reporting System (FARS) to provide information on self-reported seatbelt use, highway fatalities, and crash-related injuries among high school age youths. Zambon et.al. [56] conducted a before-and-after study to assess the sustainability of the effects of the demerit points system on seat-belt use in Italy. The authors found that the demerit points system led to an increase in seat-belt usage for drivers and front passengers, however the study also suggested that there should be an effort to target rear seat passengers as compliance for this group to wear their seat-belt remained low.

Irish Research

Between 2006 and 2007, the RSA conducted national surveys to determine seat-belt wearing for drivers, front and rear passengers. Over 10,000 vehicles were surveyed during daylight hours in summer months. Findings indicated overall front seat belt wearing was 88% in 2007 which is an increase of 2% over the summer 2006 survey and an increase of 35% since 1999 [57]. Currently not wearing a seat-belt in a vehicle is a penalty point offence (applicable for all vehicle occupants).

2.2.5 Graduated Driver License System

The impact of the graduated driver licensing (GDL) system was examined by Begg and Stephenson [58] and Begg et.al. [59]. This system was introduced to all new drivers aged 15-24 years in New Zealand in 1987 and consisted of a three-stage process. Initially a new

driver would have a 6-month learner license which required supervised driving. Following this, the driver would progress to an 18-month restricted license, with restrictions on night driving and carrying of passengers. Additionally, a blood alcohol limit of 30mg/100ml was imposed. Findings suggested that the graduated driver licensing system contributed to a reduction in road traffic collisions among young drivers and that this reduction had not diminished over time. A Cochrane review [60] of 13 studies with varying types of GDL systems for reducing motor vehicle crashes among young drivers found reductions in crash rates for all crash types had been reported. However, the magnitude of these reductions varied and with the evidence provided it was not possible to determine the specific aspects of the GDL programs that had the largest effect.

Unfortunately, Irish research analysing the effectiveness of the drivers licensing system could not be found.

2.2.6 Infrastructure Related Research

Wanvik [61] used meta analysis to estimate the effects of road lighting on Dutch road traffic accidents during the hours of darkness. The risk of injury was found to increase during darkness, and the effects of road lighting was significantly larger on pedestrian, bicycle and moped accidents than on auto-mobile or motorcycle accidents. Accident data were analysed over the period 1987-2006, and the mean effect of road lighting on injury accidents during darkness was reduced by fifty percent.

Persuad, Retting and Lyon [62] performed an empirical Bayes before-after procedure to determine the effect of the installation of centreline rumble strips on rural two lane roads in seven states - California, Colorado, Delaware, Maryland, Minnesota, Oregon and Washington. Overall, findings from this study indicated that there was a significant reduction in all injury road traffic collisions, frontal and opposing-direction side-swipe injury collisions.

2.2.7 Other Studies

Through the application of state-space models, Hermans, Wets and Van den Bossche [63] examined the impacts of weather, economic conditions and laws concerning seat-belts, speed and alcohol on road traffic collisions in Belgium. Findings indicated that the only weather factor that had a positive effect on road safety was frost. Regulations and fines on the maximum blood alcohol concentration were found to reduce the number of serious collisions and the number of fatal/serious injuries. The introduction of the mandatory seat-belt law in the front seats was also found to significantly increase road safety. Results relating to economic conditions found that decreased unemployment and increased car

registrations led to a reduction in the number of persons killed or seriously injured. The authors acknowledged that other studies had reported opposite findings for economic conditions.

Noland, Quddus and Ochieng [64] examined the effect of the London congestion charge on fatal and serious injuries both within and outside the charging zone using negative binomial models. Results from this study indicate that the effect of the congestion charge on the total casualties in London was not statistically significant. However, within the charging zone there was a significant drop in motorist casualties and a possible increase in cyclist casualties. Outside the charging zone, findings suggested that a number of areas showed the congestion charge increased motorcyclists and cyclists casualties. The authors suggested the design of the congestion charge may require changes in its design in order to achieve reductions in casualties.

Other studies have examined the intensification of enforcement [65][66][67] increased safety measures such as helmet use on motorcycles [68] air-bags in vehicles [69] warning signs to reduce collision frequency and severity [70], changes in road infrastructure [71][72], improved lighting [73] and improvement in medical technology [74].

2.2.8 Overview: Effectiveness of Policies and Measures

Numerous studies have determined the effect of an individual or small number of interventions using simple pre/post intervention comparisons[27][32][56], generalised linear models [36][38], structural change models, time series and intervention analysis [37][46][53][54].

Methodologies include ARIMA (autoregressive integrated moving average) modelling and Box-Tiao intervention analysis. ARIMA is a technique that can take both trend and seasonality into account. Box-Tiao intervention analysis has been used to check for changes in mean level of a time series as the ordinary t-test can not be used because the validity of this test fails unless the observations before and after the event varied about their means both normally with constant variance and independently [75].

Generalised linear models have also been used to evaluate the effectiveness of policies and measures. A disadvantage of using a generalised linear regression approach is that these models cannot accommodate the natural hierarchical structure of the data e.g. injuries nested within collisions and collisions nested within location. Traditional analyses are based is the independence assumption, stating that the residuals are independently distributed across all units. Hierarchical structures or nested data often cause the independence assumption to be violated. In hierarchies, the collisions on one road are often more similar to each other than the collisions on another road. These hierarchical structures have to be represented in the model of analysis, because otherwise the residuals (the variation that cannot be explained by the model) will show the same structure and

will therefore not be independently distributed [14].

Although the literature examining the effectiveness of policies and measures is not directly related to the research conducted in this study, some of the methodologies used are applicable in determining the factors associated with fatal/serious collision injuries.

2.3 Road Traffic Collision Factors: Literature

Various research studies have been conducted to gain more in-depth knowledge and comprehension of the factors influencing road traffic collisions. Findings from these studies enable policy makers to target areas of significance. Application of varying methodological approaches have been used to establish the relationships between accident frequency/severity and explanatory variables such as roadway characteristics (e.g. traffic flow) environmental characteristics (e.g. weather) and geometric design (e.g. urban junctions). Lee, Chung and Son [76] examined the complex interrelationships between these variables using structural equation models to analyse traffic collision size on highways of Korea. Road, driver, and environmental factors were found to influence accident size. Regression models to predict the numbers of fatal road traffic collisions in New Zealand lead Haynes et.al. [77] to find that the traffic flow, speed limitation and socio-demographic deprivation were the most appropriate predictors for the number of fatal collisions on urban roads, rural state highways and other rural roads. Yau, Lo and Fung [78] used logistic regression to analyse multiple-vehicle road traffic collisions in Hong Kong. Factors influencing injury severity that were found to be significant included time of the collision, driver gender, vehicle type, road type, speed limit and the number of vehicles involved.

Gaining meaningful insight into the complexities surrounding road traffic collisions and a greater knowledge of the factors that have significant influence on these collisions leads to increased comprehension, thus possibly leading to an improvement in the identification of countermeasures. Studies that have concentrated on the identification of road traffic collision factors - environmental, road infrastructure/geometry, human and vehicle characteristics shall be discussed in sections 2.3.1 - 2.3.5. Other studies (see section 2.3.6) have identified factors that influence specific types of collisions, as for example single-vehicle, rear-end, angle, head-on and side sweep collisions. Research studies which examine collision type can be used to complement studies which examine crash severity, as both address different but equally important safety questions [79]. Section 2.4 examines the different methodological approaches used to determine the circumstances surrounding road traffic collisions. This section highlights the advantages ans disadvantages of each approach.

2.3.1 Environmental Characteristics

Research studies examining the influence of environmental characteristics, have found that weather conditions have an effect on the number of road traffic collisions [80]. Brijs, Karlis and Wets [81] used a discrete time-series model to examine the effects of weather conditions on daily crash counts on major roads in three cities in the Netherlands. Results indicated that several weather effects had a significant influence in the number of collisions, for instance rainfall was found to be highly significant with respect to the number of collisions. Findings from this study were suggested to be applied in dynamic traffic management or information campaigns. Shankar, Mannering and Barfield [82] studied the effect of weather conditions and road geometry on the frequency of collisions on a 61km section of a rural highway in Washington State. The authors employed a negative binomial model to accident frequency and models of the frequency of specific accident types were estimated. Findings from this study gave insight to the combined effect of weather and road geometry on collisions. The models in this study quantified these effects on collisions and the authors gave recommendations to avoid steep grades and horizontal curves with low design speeds in areas with adverse weather conditions. Jung, Qin and Noycec [83] assessed the effects of rainfall on the severity of single vehicle collisions that occurred on interstate highways in Wisconsin. Ordinal logistic and sequential logistic models were applied in this analysis and statistically significant factors that were found to influence crash severities included rainfall intensity, wind speed, roadway terrain, driver gender and safety belt. Johansson, Wanvik and Elvik [84] assessed the risk of collisions associated with darkness in terms of an odds ratio. Findings indicated that the risk of an injury accident increased by nearly 30% during darkness in urban areas and by nearly 50% in rural areas.

Insights into environmental factors associated with road traffic collisions enable interventions and policies to be implemented that target specific areas. Thus studies in this area provide vital information for decision/policy makers. Research by Shankar, Mannering and Barfield [82] indicates the advantages of analysing specific collision types, as results provide a greater insight to the circumstances surrounding collisions relative to a single overall collision model.

2.3.2 Road Infrastructure and Geometry

Noland and Oh [85] analysed the effects of various changes in road network geometry and infrastructure in Illinois. Application of fixed effects negative binomial models to county-level time series data were used to evaluate whether improved road infrastructure and geometric design was beneficial for safety. Results from this study challenge the

benefits of many "road safety improvements" as it was found that certain infrastructural changes led to an increase in collisions and fatalities. Increases in the number of lanes increased both collisions and fatalities, and increases in lane widths led to increased fatalities. The authors note the importance of controlling for time trend in this analysis, as omission would lead to potentially misleading results. Sliupas [86] used multiple linear regression to examine the impact of road parameters and surrounding areas on traffic collisions in Lithuania. Findings suggested a strong relationship between annual average daily traffic, road barriers, road grounds and length of road section with the number of accidents in the section. Jin, Saito and Eggett [87] used a t-tests to analyse road traffic collisions that occurred on highways between construction and non-construction time in Utah. Contrary to previous research, the authors found that the mean difference between collisions that occurred during construction time and non-construction time was not statistically significant. Caliendo Guida and Parisi [88] applied generalised linear models to predict collisions for multi-lane roads in Italy. Road geometry, infrastructure and weather were examined, however human behaviour, light and vehicle characteristics were not considered in the study. Wet pavement surface was found to significantly increase the number of collisions. The authors suggested that their research may serve as a point of reference for engineers in designing/adjusting multi-lane roads. Ma, Knockelman and Damien [89] examined collision counts by severity for collisions on rural two-lane highways in Washington State. Application of a multivariate Poisson-lognormal regression model showed a statistically significant correlations between crash counts at varying levels of injury severity. Wider lanes, wider shoulders and longer vertical curves were given as suggestions to reduce collision frequencies. Haynes et al. [90] examined the influence of road curvature on road traffic collisions in England and Wales. Negative binomial models were used to determine this association and results showed that after adjusting for other risk factors collision numbers were negatively related to road curvature - more collisions occurred in districts with straighter roads. Thus findings from this study indicated that road curvature at a district level is protective. Wang, Quddus and Ison [91] examined the effects of area-wide road speed curvature on traffic casualties in England through the application of a negative binomial model. Results from this study found that road curvature is negatively associated with road traffic collisions, and that increases in average speed within a ward influenced total fatalities and serious injuries.

Research relating to road traffic collisions occurring at junctions/intersections has been conducted by several researchers. Greibe [92] developed accident prediction models using generalised linear modelling techniques to predict the number of collisions at junctions and road links in urban areas. Poisson regression models were developed for: all accidents, all injury accidents, certain types of accidents (single accidents, rear-end

accidents, crossing accidents, turning accidents, etc.). Unfortunately, only results for models based on all accidents (injury and damage only accidents) were reported in this paper, and vehicle traffic flow was found to be the most powerful variable in both the junction and road link models. Poch and Mannering [93] examined the geometric and traffic-related conditions on road traffic collision frequency at intersections using negative binomial analysis. Significant interactions were revealed in this study, with certain elements pertaining to an increase/decrease in collision frequency. Huang, Chin and Haque [94] analysed the factors that affected the severity of driver injury and vehicle damage at signalised intersections in Singapore, e.g. a Bayesian hierarchical binomial logistic model was developed and findings indicated that collisions that occurred during night time at T/Y intersections, and on right-most lane and also collisions occurring at intersections where red light cameras were installed, tended to be more severe collisions.

Most of the research studies outlined in this section apply generalised linear models to analyse road traffic collisions, however the model developed by Huang, Chin and Haque [94] has utilized the hierarchical structure of road traffic collision data, thus providing more insightful results. Section 2.4 outlines the advantages of using hierarchical regression models.

2.3.3 Human Characteristics

In addition to road and infrastructural characteristics, human behaviour has also been examined in relation to road traffic collisions. Abdel-Aty and Radwan [95] applied negative binomial modelling to road collision data over a three year period on a principal arterial in Central Florida. Results from this study indicated that drivers aged under 25 years and over 75 years had a higher tendency to be involved in collisions in heavy traffic flow, reduced shoulder widths and median widths. Female drivers experienced more collisions than male drivers on roads with heavy traffic volume, reduced median width, large number of lanes and narrow lane width. However, male drivers were more likely to be involved in collisions while speeding. Valent et.al [96] used logistic regression models to evaluate the association between driver characteristics and fatal road traffic collisions in Udine, Italy. It was found that the females had a lower risk involvement in fatal (as opposed to non-fatal) collisions than males. Findings also indicated that there was an increase in the risk of fatality on roads outside urban centres for pedestrians, motor-cyclists, pedal cyclists and car drivers. Thus the authors advocated simple interventions based on behavioural change, environmental modification and law enforcement to help reduce road traffic collision fatalities. A study conducted by Gray, Quddus and Evans [97] to analyse injury severity from road traffic collisions involving young male drivers aged 25 years and below using ordered probit models, showed that young male drivers were over-represented

in road traffic collisions relative their driving license holding level. Several factors had a statistically significant effect on the severity of collisions involving young male drivers, which include driving during darkness, overtaking, single carriageways with speed limits of 60mph and driving between Friday and Sunday.

Research containing with both injury level data (e.g. driver age/sex) and collision level data (e.g. speed limit) could adopt hierarchical models. Traditional analyses are based is the independence assumption, stating that the residuals are independently distributed across all units. Hierarchical structures or nested data often cause the independence assumption to be violated. In hierarchies, the collisions on one road are often more similar to each other than the collisions on another road. These hierarchical structures have to be represented in the model of analysis, because otherwise the residuals (the variation that cannot be explained by the model) will show the same structure and will therefore not be independently distributed [14].

2.3.4 Geographical

Aguero-Valverde and Jovanis [98] performed a spatial analysis of fatal and injury collisions in Pennsylvania using full Bayesian hierarchical models. Counties with high area deprivation was consistently correlated with collision risk, and counties with higher percentages of their population under 25 years and over 64 years, and those with increased road mileage and road density have significantly increased collision risk. Eksler, Lassarre and Thomas [99] performed a regional analysis of road mortality in Europe. Population density was found to have a significant effect on road mortality. The authors estimated a 10% increase in population density was linked to a 3.2% decrease in road fatalities. Noland and Quddus [100] conducted a spatially disaggregate analysis of road casualties in England. Findings indicated that densely populated areas were associated with fewer casualties, however areas with higher employment had more casualties from road traffic accidents. Jones et al. [101] applied multi-level negative binomial regression models to determine factors that influenced mortality and morbidity from road traffic collisions in England and Wales. Findings from this study identified a number of statistically significant factors, which included road length, resident population size and traffic flow. Local employment or shopping opportunities were not considered in this study, however holding the factors listed above constant, it was found that variations in rural land use, elevation and climate had minimal effect on road casualty numbers. The proportion of roads classified as minor roads and roads passing through urban areas were found to be negatively associated with casualty counts. Risk declined as the average road curvature increased. It was shown that statistically significant between-county variance in casualty counts was apparent.

Research studies outlined in this section that have performed a spatial analysis of road traffic collisions using hierarchical models produce findings of greater detail, as these studies can provide information relating to variation between areas/counties.

2.3.5 Vehicle Type

Research studies examining the influence of different types of vehicles on the severity of road traffic collisions provide useful information which may help policy makers to target drivers of specific vehicles.

Ramirez et.al. [102] analysed the influence of heavy goods vehicle traffic on Spanish interurban roads using negative binomial regression models. Hypothetical scenarios reducing heavy goods vehicles (HGVs) were examined thus indicating that a decrease in the total number of collisions would result from a reduction in HGV traffic. However, the authors noted that due to increased exposure as a result of the drop in HGV traffic, there would be an increase in the total number of collisions on single carriageway roads and a lower reduction on toll motorway and dual carriageway sections. De Waard, Dijksterhuis and Brookhuis [103] performed an experiment to examine the effects of increased numbers of HGVs on drivers merging in and leaving motorway traffic. A driving simulator was used to conduct this study and general linear model repeated measures were run on speed and head-way variables. Results showed that increased number of HGVs on the main road were not more adverse for elderly than for the young drivers, however elderly drivers merged into motorway traffic at a lower speed than younger drivers. An extended acceleration lane was found to have a positive effect on safety margins. Bjornstig et al. [104] examined the fatal road traffic collision injuries between passenger cars and other vehicles in Northern Sweden. Over half the fatalities that occurred involved heavy vehicles. Frequently, when HGVs were involved in a collision, multiple fatalities resulted. Findings suggested that 4% of the deaths had an indication of suicide, but this percentage rose to 8% when looking at those that crashed into trucks. With the application of logistic regression models to model the risk of fatality/hospitalisation for drivers involved in two-vehicle collisions Fredette et al. [105] found that drivers aggression in pick-up trucks, minivans and sport utility vehicles (SUVs) were statistically significant when compared to driver aggression in passenger cars. Results also showed that male drivers had higher fatality than females but had a lower risk of being hospitalised. Yau [106] examined the risk factors affecting the severity of single vehicle traffic collisions in Hong Kong. Stepwise regression models were applied to model three types of vehicles: private vehicles, goods vehicles and motorcycles. Results indicated that time of accident, driver gender and street conditions were significant factors influencing injury severity for private vehicles, whereas only seat-belt usage and weekday occurrence were significant

for goods vehicles. The factors affecting injury severity from motorcycle single vehicle collisions included age of vehicle, weekday and time of accident. The authors suggested modifying safety measures to target drivers by vehicle type, thus helping to reduce severe road traffic collisions. Kim, Kim and Son [107] analysed road traffic collisions in the United States, and found that the probability of survival was most likely influenced by vehicle characteristics such as the type of vehicle, presence of air-bags, vehicle weight and age of vehicle. Whereas, driving behaviour is most likely to influence the probability of being involved in a road traffic collision.

Unfortunately relatively few studies in this section have examined vehicle types involved in different types of collisions. Research conducted by Yau [106] indicates that factors affecting the injury severity for the single vehicle collisions involving private vehicles differ from the factors for goods vehicles and motor cycles.

2.3.6 Collision Type

Analysis of hit-and-run accidents in Asia were undertaken by Tay, Rifaat and Chin [108]. The authors modelled the effects of roadway, environmental, vehicle and driver characteristics on hit-and-run collisions. Applying a logistic regression model, they found that hit-and-run collisions were more likely to occur at night, on a bridge, flyover, bend, and on straight roads. Drivers from neighbouring countries were more likely to leave the scene of an accident than drivers resident in the country. Human characteristics showed that drivers in the 45-69 year age group, male and from an ethnic minority group were likely to leave the scene of the accident. Kim et.al. [109] apply binomial multi-level models to angle, rear-end and side-sweep collisions on 91 two-lane rural intersections in the State of Georgia. Findings from this study suggest that a hierarchical structure is present in the data and that intersection-level fixed effects capture a significant portion of the variation across intersections for both angle and rear-end collisions. This study builds on previous research conducted by Kim, Washington and Oh [79], which applied Poisson and negative binomial models for different crash types. This analysis showed that annual average daily traffic, the presence of turning lanes and the number of driveways had a positive association with each collisions type. Data relating to single vehicle collisions and environmental weather data were unavailable for this analysis. Garber and Kassebaum [110] evaluated crash rates and casual factors for high risk locations on rural and urban two-lane highways in Virginia. Fault tree analysis* and negative binomial and Poisson models were employed to determine which factors were statistically significant. Findings

*A fault tree is a hierarchical model that is used to analyse risk. A fault-tree allows the researcher to determine the minimum cut set, which is the shortest chain of events that lead to the failure identified the associated casual factors

from this report suggested that run-off-the-road collisions were the most frequent collision type, followed by rear-end, angle and deer collisions. Increased curvature on both rural and secondary roads lead to a decrease in run-off-the-road collisions. On rural primary highways, rear-end collisions decreased with turning lanes and increased with the presence of stop-lights. Increasing annual average daily traffic (AADT) lead to an increase in head-on collisions on rural primary and secondary highways and increasing lane widths tended to decrease these collisions.

The advantage of developing models to examine different collision types is that these models can provide insight into the factors associated with e.g. rear-end collisions which may 'over represented' at certain locations e.g. junctions. Separate regression models for specific types of road traffic collisions have the potential for providing greater explanatory power relative to single overall crash frequency models [82]. It is reasonable to suspect that the probabilities of collision occurrence by collision type are associated with roadway infrastructure, vehicle, and environmental factors in different ways because of the suspected heterogeneity in underlying causal mechanisms associated with different collision types [109].

2.4 Statisticial Methodology: Road Traffic Collision Factors

Section 2.3 has shown that numerous studies with varying methodological approaches have been conducted to establish the relationships between collision frequency and explanatory variables such as roadway characteristics (e.g. traffic flow) environmental characteristics (e.g. weather) and geometric design (e.g. urban junctions). Methodological approaches include: linear models; generalised linear models; generalised linear multilevel models; zero-inflated models and hurdle models. The underlying concepts behind these models differ and there are advantages and disadvantages associated with each method.

2.4.1 Linear Regression Models

Multiple linear regression models have been used to identify the factors that contribute to the cause of a road traffic collision [111] and also assess the associations between regional differences in traffic mortality, case fatality and accident rates with road infrastructure, medical care and socio-demographic factors [112], road traffic collisions and road-user behaviour [113]. Simple linear regression models have been used to determine the mortality and morbidity pattern of collision [114]. However, linear regression models are restrictive

in nature as these models make the assumption that the data follow the normal distribution where additivity, linearity, the independence of the errors and homoscedacity are satisfied. The nature of road traffic collisions (often sporadic, discrete and random events) makes the data more akin to following a Poisson distribution. Comparing two conventional linear regression models and two Poisson models to model the relationship between vehicle collisions and highway geometric design indicated that test statistics derived from the conventional linear models were questionable as these models lacked the distributional properties required to describe adequately discrete, non-negative vehicle collision events [115]

2.4.2 Generalised Linear Models

Classical generalised linear models (GLM) are widely used in road traffic collision studies. Logistic regression models [106][96][116] and ordered probit models [117][118] have been used to determine the factors affecting the severity of collisions/injuries. Ucar and Tathdil [119] compared the results obtained from three discrete models, namely linear probability model, binary logit model and binary probit model. The study analysed motorcycle accidents in Turkey. Findings indicated that the linear probability model was unsuitable to model these collisions in most cases due to assumption violations, however application of weighted least squares technique eliminated some of these violations. The authors concluded that the results obtained from the three models were very similar in terms of the signs of the coefficients.

Poisson models have been employed in studies concerned with the factors affecting the numbers of road traffic collisions. Poisson regression models must satisfy the mean equal to variance criterion thus if violated over/under dispersion may be present. If over-dispersion is present (i.e. the variance is greater than the mean), the Poisson model is deemed inappropriate as the likelihood of accident occurrence may be incorrectly estimated [88]. Solutions to over-dispersion include the modification of the pure Poisson distribution into the generalised/quasi-Poisson [120] [80]. Explanatory variables that appear to be significant from the over-dispersed Poisson can be shown to be not significant when the more appropriate quasi-Poisson model has been adjusted [121].

Several research studies have adopted negative binomial regression models in order to deal with over-dispersion[122][123][101][124][82][93]. If residual over-dispersion questions the relevance of the negative binomial model and expected relationships are not satisfied then a generalisation of the negative binomial model by adding an over-dispersion parameter gives the quasi-negative binomial model. This model is deemed a more suitable model in this situation [125]. If data are suspected to belong to different groups, it has been suggested that Poisson and negative binomial mixture models are employed before

the traditional negative-binomial model as these mixture models can provide the nature of the over-dispersion in the data [126]. Alternatively, if under-dispersion is present in the data set, Gamma models [127] or Conway-Maxwell-Poisson generalised linear models (COM-Poisson) have been employed [128] . The latter model can also accommodate over-dispersed data, thus providing a flexible approach for performing analysis on count data [129]

2.4.3 Zero-inflated Models and Hurdle Models

If a large percentage of sites in the study have been observed to have zero collisions during the study period (i.e. an over-representation of zeros) then the distribution of collision frequencies, including zero counts may not follow the traditional Poisson and negative binomial distributions [88]. Zero-inflated count models and Hurdle models have been adopted to deal with this issue of excess zeros. Zero-inflated models are generally used if the data contains excess structural and sampling zeros, whereas Hurdle models are typically used if the data contains only sampling zeros. Zero-inflated models have been adopted in research studies as an alternative to traditional models as both the Poisson and negative binomial models do not deal with the possibility that more than one under-lying process may be affecting collision frequency likelihoods [130]. The zero-inflated Poisson and zero-inflated negative binomial both account for the influence of zero collision observations often present in the frequency data. Zero-inflated models have been adopted in many diverse research areas including manufacturing [131], sociology [132] and collision research [133][134][135][136][137]. However, application of zero-inflated models in highway safety research has been criticised for the assumption of a dual-state process - a true-zero and a non-zero state. It has been argued that excess zeros in collision data does not imply that an underlying dual-state process exists as many conditions could contribute to this situation, some of which include sites with a combination of low exposure, high hetregeneity and sites categorized as high risk [138][139].

2.4.4 Multilevel Generalised Linear Models

As can be seen in previous sections, the application of classical GLMs for road traffic collision research is widely practised. However, a draw-back of GLMs is that these models cannot accommodate the natural hierarchical structure of the data. Failure to account for this hierarchy may lead to inaccurate results due to the over simplification of the complex reality of the data [140], as "GLM underestimates standard errors and thus provides erroneous too narrow confidence intervals" [141]. Multilevel models were developed to analyse hierarchically structured data. A hierarchy consists of lower-level observations

nested within higher level(s) [142]. Multilevel models, also known as hierarchical models or random coefficient models are extensions of classical regression models in which the data are structured in groups and groups can vary by group [143]. Road traffic collision data naturally lends itself to the structure applied in multilevel models, for instance "driver's characteristics are nested within crashes, crash characteristics are nested within site characteristics, site characteristics are nested within regional characteristics, and so forth" [109]. Multilevel modelling techniques have also been recommended as best practice[†].

A number of studies have developed/applied multilevel models to examine road traffic collisions. Jones and Jorgensen [140] developed a multilevel model to analyse fatal and serious casualties from road traffic collisions in Norway. Findings from this study showed a statistically significant residual variation in casualty outcomes between separate collisions and varying geographical locations, thus indicating the presence of intra-correlation in the data. Failure to acknowledge this correlation may lead to poorly estimated models. Lenguerrand et.al. [141] analysed road traffic collision severity in France. This study employed three different types of models - logistic, multilevel logistic and generalised estimating equations (GEE) models. The multilevel logistic model was found to be the most efficient model. As previously mentioned in section 2.3.6, Kim et.al. [109] show how multilevel models can be applied to analyse different collision type. Binomial multilevel models estimated for varying collision types that occurred at two-lane rural intersections in the State of Georgia.

Despite the advantage of multilevel models, these models are not without limitations - the presence of intra-correlation cannot be explained by multilevel models, convergence issues and estimating bias may be an issue if there a low number of sub-clusters per cluster [141] and technical limitations exist due to the estimation of non-linear models using iterative generalised least squares [140].

2.4.5 Bayesian Approach

Bayesian models have been employed in several studies to analyse road traffic collision data. Mountain, Fawaz and Jarrett [144] developed prediction models to predict collisions that occur on roads with minor junctions. Both single and dual carriageway roads in urban and rural areas in the U.K. were examined in this study. Generalised linear models

[†]Project SafetyNet was completed in October 2008 SafetyNet was an Integrated Project funded by Director-General of Transport and Energy (DG-TREN) of the European Commission. The objective of the project was to build the framework of a European Road Safety Observatory, which will be the primary focus for road safety data and knowledge, as specified in the Road Safety Action Plan 2003. The Observatory will support all aspects of road and vehicle safety policy development at European and national levels. http://erso.swov.nl

and Empirical Bayes (EB) models were employed in this study. Results indicate that EB models were the only models that produced unbiased estimates of accidents for high risk collision sites.

2.4.6 Hierarchical Bayesian Approach

Application of a Bayesian approach can be seen in many road traffic collisions studies - [145][146][147]; [148][149]

Application of hierarchical Bayesian models have been applied in road traffic collision studies as these models can deal with the issue of over-dispersion due to unobserved hetrogeneities. These models can incorporate site-specific attributes and time and/or space patterns in the data [150]. Huang, Chin and Haque [94] developed a hierarchical Bayesian binomial logistic model to determine the factors affecting the severity level of driver injury and vehicle damage in road traffic collisions that occur at signalised intersections in Singapore. Tunaru [151] developed a multiple response model for counts, which could support complex correlation structures. The model was used analyse road traffic collisions on single carriageway link sites in Kent.

Section 2.3 indicates that relatively few research studies (in comparison to traditional GLM) have adopted hierarchical Bayesian approaches. Studies that have employed these models have examined road traffic collisions severity [94][141][152],[151], spatial and regional analysis of collisions [98][99] and collisions at intersections [153]

2.4.7 Overview

Sections 2.3-2.4 show the vast range of research using varying statistical techniques to analyse road traffic collisions. In compliance with best practice recommendations [14] and existing evidencce supporting the examination of different collision types [109][79], this research aimed to develop hierarchical regression models from a Bayesian perspective to assess the human, environmental and infrastructural factors associated with fatal/serious single vehicle and multi-vehicle injuries.

2.5 Identification of Hot Spots: Literature

Studies have adopted various methodological approaches to identify hot spots. Hot spots are sometimes referred as hazardous road locations [154]; hotspots [155]; sites with promise [156]; high crash corridors/locations [157] [158] or black zones [159]. There is no universally accepted definition of a hot spot, but generally this term is used to describe locations that have an abnormally high number of crashes [160]. In 2005 the European

Union Research Framework Program 6 awarded 2.6 million Euro to a major project 'Road Infrastructure Safety Protection - Core-Research and Development for Road Safety in Europe and Increasing Safety and Reliability of Secondary Roads for a Sustainable Surface Transport' (RIPCORD-ISEREST). The main objective of RIPCORD was to give scientific support to the European transport policy to reach the 2010th transport road safety target (to halve the number of road fatalities) by establishing best practice tools and guidelines for road infrastructure safety measures [161] As part of this project a report indicating a state-of the-art approach to road accident hot spot management was produced. State-of-the-art referred to the best approaches from a theoretical perspective, but were not necessarily identical to approaches that were used in practice [162]. "This state-of-the art approach served as a benchmark for assessing current approaches to black spot management in some European countries" [154]. Knowledge to date indicates that there is no European country that consistently employs a state-of-the-art approach for identifying hot spots, thus prompting the development of a step-by-step state-of-the-art approach [162] The elements of this approach have been based on the theoretical definition of a hazardous road (hot spot): "a hazardous road location is any location that has a higher expected number of accidents than other similar locations as a result of local risk factors present at the location" [154]. This state of the art approach suggests identification of hot spots in terms of the expected number of collisions and that the best estimate would be obtained via Bayesian techniques. A before-and-after design should be employed to examine the effects of hot spot treatment [162].

Research on road traffic collision hot spot identification has followed a number of different methodological paths over the last decade. A broad categorisation of the methodologies employed in locating accident black spots offers 3 typical approaches:

1. GIS to identify areas with apparent concentrations of road traffic collisions;

2. application of a generalised linear model (either Poisson or negative binomial or more recently empirical Bayes) to model the distribution of road traffic collisions and thereby identify areas with excessive risk;

3. accident cluster detection methods such as the global methods (K–function or autocorrelation) or either of two focussed methods (kernel density estimation and the scan statistic).

The accident models based on the negative binomial or the empirical Bayes method offer the opportunity to incorporate relevant covariates in an attempt to understand (and simulate) the circumstances in which accidents cluster in space and over time. However, the focused cluster tests are innately more powerful, albeit historically this was at the expense of understanding what factors contribute to such high–risk locations.

2.5.1 Irish research

In Ireland there has been comparatively little direct research on road traffic collisions. A report by McCutcheon Hogan Planning Consultants and the Dept. of General Practice National University of Ireland Galway set out to examine the geographical distribution of road traffic accidents in relation to ambulance provision within the areas covered by the Western and North Western Health Boards. Walsh, Trace, Nicholson and Kelly [163] studied the relationship between childhood pedestrian injuries in Ireland and the small-area level deprivation and found that children in deprived wards have a fivefold increase in pedestrian injury. In the context of this study an NRA report entitled "High accident locations, 1996 - 2000: The inter-urban national route network" is the more relevant piece of research. The author employs a negative binomial model to derive an expected number of accidents per discrete road segment (1,922 of these, each with similar road characteristics) and then compares the model findings to the actual observed numbers of fatal and serious accidents to identify large discrepancies [164].

An Garda Siochana in conjunction with the National Roads Authority, Ordnance Survey and the Local Government Computer Services Board have compiled a list of collision prone zones [165]. These zones consist of road sections measuring approximately 5 to 8 kilometres which have been identified as being predisposed to collisions. Analysis of these zones was conducted on collision history data over a 10 year period and a weighting system was applied based on the collision severity. EuroRAP (European Roads Assessment Programme) [166] was formed by motoring organisations and road authorities across Europe and produces maps that indicate the risk of traffic collisions that cause death and life-threatening injuries. EuroRAP is not-for-profit association registered in Brussels and the maps produced use real collisions and traffic flow data to measure and map the rate at which fatalities and injuries occur. The first risk map for Ireland was produced in 2005 and subsequently was updated in 2008. The latter publication indicated that "there are now no High Risk sections on the Island of Ireland" [166]. Similar road assessment programmes exist for Australia (AusRAP), New Zealand (KiwiRAP) and United States (usRAP). iRAP (international Roads assessment programme) is the umbrella organisation for the previously mentioned road assessment programmes [167].

2.5.2 International research

A wide variety of methodological approaches have been adopted to identify hot spots. A number of research studies have been centred on road segments, specific junctions or administrative units [168]. Several studies have adopted ranking criteria, some of which include ranking accident count, frequency or by severity weighted counts/frequencies.

A research report conducted by Kentucky Transportation Centre identified high crash corridors in twelve highway districts through the use of a ranking system that considered a number of attributes for each corridor. Counter measures were then suggested by the authors to address the problem areas identified on the corridor. [157]. Mustakim [111] identified black spots by ranking accident point weightage and ranking of the top ten accident sections. Hauer et al. [169] compared five alternative ranking criteria in terms of cost-effectiveness. The study was based on data for rural two-lane roads in Colorado and results indicated that the sites that lead to the most cost effective projects were sites with most collisions/most collision severity-weighted collisions. Geurts et.al. [170] performed a sensitivity analysis to determine the advantages and disadvantages of the current methodology to rank black spots in Flanders, Belgium, which only takes the most serious injury per collision into consideration as opposed to all injured occupants. Findings from this study indicate that bias that occurs (when the number of occupants of the vehicles are considered) can be corrected through the application of weight to the severity of the collision. Brijs et.al. [171] proposed a hierarchical Bayes model to rank intersections according to their level of hazard. The model proposed is based on three-variate Poisson distribution with different covariates for each pair of variables. The authors acknowledge the limitations of the Poisson assumption, however suggest that more advanced models may be constructed using a similar process. Schluter, Deely and Nicholson [172] employed a Bayesian hierarchical model for ranking and selecting hazardous accident sites. Analysis was applied to fatality collision data in Auckland, New Zealand.

The local-autocorrelation method requires the division of the road network into basic statistical units of equal length. Black and Thomas [173] examined traffic accidents along Belgium's motorways using network autocorrelation analysis to handle segmented counts and complications arising from connections between segments e.g. at road junctions. Geurts, Thomas and Wets [174] undertook a study to determine the characteristics of accident black spots for accidents occurring outside so-called 'black zones' in a peri-urban region of Belgium. Their methodology was based on a data mining technique known as 'association algorithm', which is a technique of frequent item sets (data mining) and is applied for automatically identifying accident circumstances that frequently occur together, for accidents located in and outside 'black' zones. The authors did identify certain collision characteristics that were considered more typical of those occurring in the 'black zones' such as collisions left-turns at signalized intersections, collisions with pedestrians, loss control of the vehicle (run-off-roadway) and rainy weather conditions. Moons [175] identified accident hot spots on highways in a province in Flanders using a local indicator of spatial association. Alternative methodological approaches to identify

and predict black spots have included neuro-fuzzy inference systems [176], application of life-time risk concept [177] and generation of a continuous risk profile for highway collisions [178]. Hwang et al. [179] applied the continuous risk profile methodology to identify high collision locations on free-ways in the San Francisco Bay area under wet pavement conditions.

Several studies have evaluated varying methodological approaches which have been used in the identification of black spots. Hauer and Persuad [180] proposed measuring the performance of methods for identifying hazardous locations by false identifications. Cheng and Washington [155] compared three methods: simple ranking of sites by order of collision frequencies, comparison of counts between similar crash locations to identify sites which exceeded expectation and empirical Bayes (EB) method. In this study properties of observed collision data were used to simulate collision frequency distributions at hypothetical locations. Various collision factors were used to simulate a host of real world conditions. The authors found that the EB approach outperformed the alternative methods in identification of high risk locations under a variety of realistic conditions. Elvik [181] replicated the research conducted by Persaud et al. [182] and formally compared five techniques for identifying hazardous locations. Sensitivity and specificity criteria were used to determine the diagnostic performance of the different approaches. The results from this study indicated that the EB estimates of safety provided are more reliable than traditional methods such as accident counts, accident rates and the combination of accident count and rate. Miranda-Moreno, Labbe and Fu [150] introduced a Bayesian multiple testing-based approach to identify hotspots, namely Bayesian test with weights and a Bayesian test controlling for the false negative rate or false discovery rate. This study used high-way railway grade crossings data and adopted a hierarchical Poisson framework. Results indicated that model choice may have an important impact on the results on the process of hotspot selection. Cheng and Washington [183] used three years of road section accident data in Arizona to demonstrate four new and one established quantitative hot spot identification evaluation tests to evaluate the performance of four hot spot identification methods. The authors argue that these evaluation tests, namely, the site consistency test, the method consistency test, the total rank differences test, the Poisson mean differences test and the false identification test offer an improved ability to evaluate hot spot identification methods versus comparing false positives and false negatives. The results from this study indicate that the Empirical Bayes method was the most reliable method for identifying hotspots and the accident rate method consistently performed the worst. A recent paper by Huang, Chin and Haque [184] which analysed intersection crash data collected in Singapore, indicated that the EB and Full Bayes (FB) approaches performed significantly better in safety ranking than the naive

ranking method. The authors also found that the FB method using hierarchical models significantly outperformed the EB approach in correctly identifying hazardous sites.

Several researchers have applied methodologies for detecting clusters. Yamada and Thill [185] designed two test approaches, namely - a two dimensional planar K-function with network constraints and a single dimensional network K-function. Accident data from three regions of New York state were studied. Jones, Langford and Bentham [186] also used K-function to examine RTAs in Norfolk, England between 1987 and 1991. Their intention was to examine the importance of various factors, including the role of ambulance response time, in determining the likelihood of survival for each casualty involved in an road traffic collision in the county. The geographical location of the clusters cannot be determined by the K-function methodology, which is a significant draw-back with this methodology [187]. Ng, Hung and Wong [188] employed GIS, cluster analysis and a negative binomial regression model to determine the relationship between the number of collision events and the potential causal factors in Hong Kong. Accident risk was computed by the EB approach. Noland and Quddus [100] used highly disaggregated spatial units (wards) in the UK and analysed area specific variables to establish which was associated with road traffic casualties. The authors found that areas with higher unemployment tended to have more traffic casualties.

The kernel method places a grid (or row for 1D analyses) of equal-sized cells over the road network and counts the number of accidents in the neighbourhood of each grid cell. [189] Sabel et al. [190] developed a method for using kernel density estimation (which is a non-parametric method that uses a density estimation technique), whereby a distribution of discrete point 'events' were transformed into a continuous raster surface, to identify road traffic hot spots in Christchurch New Zealand. A global relationship was established by calculating the distance from each collision to the nearest junction. This relationship was then used to assign a collision risk rating to each square meter of road. An overall indication of the hazard level for each road section was established by combining flow data with the crash risk rating. Xie and Yan [191] developed a network kernel density estimation approach for characterizing the spatial patterns of traffic accidents on roadways. Traffic collision data from a road network in Bowling Green, Kentucky was used to test the approach. The test results indicate that as the planar network kernel density estimation covers space beyond the network space and is likely to overestimate the density values thus the new network kernel density estimation is more suited for density estimation of traffic accidents. However the authors note that both the new network kernel density estimation approach and the planar kernel density estimation have a fundamental drawback - there is no indication of a density threshold above which hot spots can be confidently stated as no statistical significance is employed in the process.

Application of GIS and kernel density analysis have also been applied to traffic accidents on highways in the city of Afyonkarahisar, Turkey [192] and to study the spatial patterns of injury related road accidents in London [193]. The latter study added environmental data to hot spot cells via K-means clustering. Flahaut et al. [159] compares two methods for identifying black zones along a Belgium road, namely, spatial autocorrelation indices (which are a decomposition of the global Moran I index) and kernel density estimation. Although each method starts from different conceptual approaches results from this study indicate that both techniques may provide quite similar results under a specific choice of parameters. Steenberghen et al. [189] compared one dimensional and two-dimensional clustering techniques (kernel method and local spatial-autocorrelation) on accident data in the Belgian town Mechelen. The authors indicate that linear spatial clustering techniques appear more applicable when traffic flows can be clearly identified along a route and that two-dimensional techniques enable the identification of accident-prone areas for dense road networks with diffuse traffic patterns.

M. Kulldorff [194] developed a spatial scan statistic for the detection of clusters in a multi-dimensional point process. A natural Bayesian extension to Kulldorff's spatial scan statistic was proposed by Neill, Moore and Gregory [195][196]. The authors indicate that the Bayesian spatial scan has several advantages over the frequentist approach some of which include higher detection power and faster computation. In a recent paper Jiang, Neill and Cooper [197] developed a Bayesian-network-based spatial scan statistic called BNetScan. The authors compared the performance of three spatial cluster detection methods in the context of disease-outbreak surveillance. Results indicated that BNetScan outperformed the other two methods (Kulldorff's spatial scan statistic and Bayesian spatial scan) in the majority of cases both in terms of outbreak detection and sub-region detection. Zhang and Lin [198] propose model-based likelihood scan statistics - the likelihood ratio (deviance) scan and the Wald scan, and they show that this Wald based spatial scan statistic can be applied for cluster detection in the presence of overdispersion and that the likelihood ratio scan statistic is equivalent to Kulldorff's spatial scan statistic when no covariates are present. As the model-based scan statistics offer more flexibility than the spatial scan statistic the authors hope that these approaches will be applicable in many studies on Poisson count data. Application of a spatial scan statistic for data that is continuous or ordinal in nature have also been proposed. Kulldorff, Huang and Konty [199] present a scan statistic where the likelihood is calculated using the normal probability model. The authors apply this approach to identify geographical clusters of low birth weight in New York city. A spatial scan statistic for ordinal data was proposed by Jung, Kulldorff and Klassen [200]. This methodology was applied to prostate cancer grade and stage data from the Maryland Cancer registry. Scan statistics

are also available for survival data [201][202].

Patil and Taille [203] developed a novel upper level set (ULS) scan statistic for "hot spot" detection (referred to by the authors as "critical area" detection) employing an 'adaptive' scan statistic. The particular merit of this latter modification is the ability to adjust the standard fixed-window scan to take one or more explanatory variables into account. In a follow-up paper by Patil et al. [204] the theory and design implementation for the upper level set (ULS) scan statistic is discussed for purposes of hotspot detection. The statistic may be extended to the bivariate and multivariate case where multivariate hot spots are represented by connected cells that appear in the intersection of the univariate hotspots of all variables. The ULS methodology is unsuitable for the identification of road traffic collision hot spots as the ULS approach applies to cases recorded in connected spatial cells as opposed to a linear network. If the road traffic collisions were considered in this manner, the problem of collisions occurring on different roads (which are in close proximity to each other, but not necessarily connected) would result in artificial identification of hot spots as the collisions (which are not connected) would be combined together for the analysis. An alternative approach to the upper level set scan is introduced by Janeja and Atluri [205]. They propose a version of a scan statistic to identify anomalous windows along a linear path while adjusting for contextual information. The authors apply this to the identification of road traffic accident hotspots along highways in New Jersey (see details Chapter 3, section3.1.3, P.44). Pacifico et al. [206] implement a general method, also based on the scan statistic, to detect spatial clusters while, crucially, controlling for false positives. They provide a detailed discussion of the theory and an illustrative example. A recent paper by Steenberghen, Aerts and Thomas [187] proposed a methodology to compute spatial concentrations of point-based events on a network. This clustering methodology is based on moving segments and distances along a network. Dangerous zones were identified on the Brussels' road network. The authors' argue that this new methodology has several advantages - "the use of network distances as opposed to Euclidean distance gives a more realistic measure of spatial correlation for events that are the results of movements along a network" and that the use of moving segments does not suffer from boundary effects and "does not necessitate the division of the network into segments of equal length". The calculation of the 1-D distance of points along a network is highly relevant for road traffic collision analysis as it eliminates the issue of collisions which fall on a non-contiguous road section being incorporated. In this study the authors computed a 'dangerousness index' which gave a high weighting to collisions close to the point of measurement and the weighting decreased with distance, thus several collisions that are located in near vicinity of the point of measurement had high dangerousness indices. The disadvantage to this approach is that the dangerousness is

not measured continuously, but measured at certain intervals, which are then interpolated over the whole road network. Shi and Janeja [207] proposed an approach for discovering anomalous windows using scan statistics for linear paths (SSLIP). The approach involved three steps, namely - Cross path discovery; Anomalous window discovery and Monte Carlo simulations. Results from this study show that SSLIP was effective for the identification of anomalous traffic accident windows along multiple intersecting highways (see details Chapter 3, section3.1.4, P.46).

S. Shiode [208] proposed a method for constructing a set of quadrats as a basic aggregation unit to be used for a variety of spatial analyses for aggregated data. Sensitivity analysis showed that the network quadrats outperformed the planer quadrats at a comparable scale. The author indicates that the most effective application of the network-based quadrat method is to a micro-scale data set, as the difference between the network distance and the euclidean distance becomes more significant when dealing with a data set of a finer scale in a relatively small study area.

Pei et al. [209] proposed a density-based cluster method (DECODE) that is based on reversible jump MCMC strategy, to discover clusters of different densities. Despite only seismic data being used in the applications, the authors believe that spatial data such as traffic accidents may be analysed with their proposed method due to their resemblance in the data formation and the spatial distribution.

Software

A number of tools such as SANIF [210], SANET (Spatial Analysis on a NETwork) [211][212] and Crimestat [213] have been developed for spatial analysis in a GIS environment. SaTScan was developed by Martin Kulldorff to analyse spatial, temporal, and space-time point data using the spatial, temporal or space-time scan statistics [214]. SANET is a GIS based tool-box which was designed to analyse spatial phenomena (e.g. traffic accidents) that occur on networks . Some of the tools in this tool-box include construction of a node adjacency data set, network K-function/cross K-function method, network Voronoi diagram, nearest-neighbour distance method and network Huff model. Recently, Okabe et al. have developed a kernel density estimation method for estimating the density of points on a network and have implemented this in the GIS environment [215]. It has been reported that spatial analysts in more than 50 countries use SANET [216]. CrimeStat is a Windows spatial statistics program that is used for the analysis of crime incident locations. This program can perform a number of routines including interpolation, hot spot analysis, space-time analysis and interpolation. Some of the routines within 'hot spot analysis' include hierarchical nearest neighbour clustering, adjusted nearest neighbour hierarchical clustering, K-means clustering and the local Moran statis-

tic. SaTScan software can employ a number of different models including a Poisson-based model, a Bernoulli model, an ordinal model, an exponential model or a normal model. This software has been employed in a wide variety of research fields, as for example medicine, epidemiology, criminology, ecology and forestry. Kulldorff's circular spatial scan statistic [194] and flexible spatial scan statistics developed by Tango and Takahashi [217] are used in the FleXScan software to analyse spatial count data [218]. This software uses a Poisson model and the data may be aggregated at e.g. census tract/county etc.. Aside: alternative software packages include R, SPlus, SAS, SPSS, Systat, Clusterseer and SpaceStat.

2.5.3 Overview: Hot Spot Identification

Sections 2.5.1-2.5.2 show the vast range of research (and comparatively little Irish research) to identify hot spots.

Global methods to identify hot spots include Ripley's K-function, Getis's G-statistic and Moran's I, these methods examine whether a given point distribution differs from a random distribution. A limitation of these methods is that they do not identify the location of hot spots within the distribution [187]. Planar K-function and network K-function have also been used to analyse road traffic collisions [185], however, similar to the above methods, the location of the hot spot is not identified. The kernel method and the local spatial-autocorrelation method are two methods that have been widely used to analyse road traffic collisions [173][190] [191] [159][189] The local-autocorrelation method requires the division of the road network into basic statistical units of equal length. The kernel method places a grid (or row for 1D analyses) of equal-sized cells over the road network and counts the number of accidents in the neighbourhood of each grid cell. If the grid covers the total study area, "the density of the road network is then ignored: some grid cells include a large number of road sections, while others only include a few or even no road sections. The result is therefore biased by the actual length of road segments in, or in the neighbourhood of, each grid cell"[189]. A recent paper by Steenberghen, Aerts and Thomas [187] proposed a methodology to compute spatial concentrations of point-based events on a network. This clustering methodology is based on moving segments and distances along a network thus the use of moving segments does not suffer from boundary effects and does not require the division of the network into segments of equal length. The disadvantage to this approach is that the dangerousness is not measured continuously, but measured at certain intervals, which are then interpolated over the whole road network.

As previously mentioned, one of the main aims of this research is to develop the required efficient statistical methodology for identifying road traffic collision hot spots/corridors

along the road network in Ireland. Scan statistics were selected as the appropriate statistical methodology to identify these collision hot spots/corridors Scan statistics were developed in 1965 by Joseph Naus [219], thus have are long established history of being applied in many diverse areas of research astronomy, epidemiology, genetics, electrical engineering, biosurveillance, physics and computer science [220] The method involves scanning the point data with a scanning window of fixed size in the time period to identify the maximal number of point events within the scanning window. In 1996, Neville Nagarwalla [221] proposed a variable window scan statistic for point data (i.e. the window did not require a pre-specified fixed value) to determine if events are closely located to each other in time. Unfortunately, these scan statistics in their original format do not identify the spatial location of cluster, however this research utilizes the underlying concept of Nagarwalla's variable window scan statistic but adapts distance (km) along a linear network (road) as distinct from distance (days) in (linear) time. The reason for taking this approach as opposed to using Kulldorff's space-time scan statistic is due to the ability to adopt Nagarwalla variable window scan statistic to identify hot spots along a linear road network. Kulldorff's space-time scan statistic is not restricted to network, thus cannot identify hot spots on individual roads. In addition to adapting Nagarwalla's variable scan statistic to road traffic collisions, this research develops a systematic approach to identify multiple collision hot spots/corridors along individual roads. Currently, Nagarwalla's scan statistic only identifies the most likely hot spot. Chapter 3 provides a description of this novel systematic approach.

2.6 Literature Overview

The literature review was sectioned into four thematic areas - legislative reform/ policies/ measures for road safety; effectiveness of road safety initiatives; explanatory factors for road traffic collisions and hot spot identification research. The united effort to combat fatal/serious road traffic collisions can be seen through the vast array of road safety programmes, interventions and establishment of dedicated organisations that focus on reducing collisions.

Although legislation introduced and research on the effectiveness of policies/measures is not directly applicable to the research undertaken in this study, it helps portray a comprehensive overview of work/research in the area of road safety International research on the effectiveness of policies/measures indicates that there are many situations where road safety interventions have reduced injuries/traffic collisions [222][223], however an issue arises when this reduction cannot be sustained, and in many cases injury levels have reverted to near pre-intervention levels [35][45]. Additionally, some interventions

have resulted in undesirable side-effects as for example increased casualties for cyclists and motorcyclists [64]. With reference to the introduction of the penalty point system in the Republic of Ireland in 2002 - Irish studies have indicated that in many circumstances there has been a reduction in the injuries/hospital activity associated with traffic accidents in the initial six-month period after the introduction of the penalty point legislation but this reduction was not sustained [31][30][33]. In contrast, a reduction in maxillofacial injuries continued to be apparent in the second six months after the penalty point legislation was introduced [29]. Additional research in the effectiveness of policies/measures could contribute and expand existing knowledge on road traffic collisions, as currently very few studies have assessed the effect of the multiple interventions on mortality and morbidity and none have assessed this effect in the Republic of Ireland.

Examination of the literature pertaining to factors influencing road traffic collisions, fatalities and injuries is suggestive of a complex process that has many varying factors which cover a diverse number of areas - environmental, road infrastructure and geometry, human characteristics and vehicle type. Identification of these factors gives meaningful insights into collisions thus giving an improved comprehension of the collision process. Various methodological approaches have been used to establish the relationships between accident frequency/severity and the aforementioned factors. For example, multinomial logit models [224]; logistic regression models [106][96][116]; ordered probit models [117][118]; mixed logit models [225]; Poisson and negative binomial models [122][82][93][124][123][101][226]; zero inflated models [133][134][135][136][137]; multilevel models [140][141][109]. Lord et. al [227] reviews various statistical methodologies applied to collision data.

Hierarchical models have been recommended as best practice in road traffic collision analysis [14] and research recommendations suggest analysis of collisions based on different collision types [109]. In comparison to international research, very few studies have conducted research of road traffic collisions in Ireland. The research in this study, develops models for fatal/serious single vehicle and multi-vehicle collisions, thus providing meaningful insights to the circumstances surrounding these collisions.

Scan statistics were selected as the appropriate statistical methodology to identify collision hot spots/corridors in Ireland. This research tests the utility of known methods, identifies limitations and develops an approach to overcome limitations while maintaining strengths of existing methods. Relatively little work on scan statistics has been developed to identify hotspots on road networks. Most development in the area of scan statistics has focused on spatial development for identifying disease clusters. Thus through the development of the scan statistic to detect multiple collision hot spots/corridors occurring on Irish national routes and the analysis of multi/single vehicle collision injuries will

provide novel insight to road traffic collisions in the Republic of Ireland. Chapter 3, provides a detailed description of the scan statistics used and developed in this research.

Chapter 3

Hot Spot Identification

As illustrated in the literature review, scan statistics provide a useful and efficient tool to identify hot spots. Scan statistics have been applied in may diverse areas of research - astronomy, epidemiology, genetics, electrical engineering, biosurveillance, physics and computer science [220]. With reference to road traffic collisions, temporal and space-time scan statistics can be used to identify road collision hot spots over time and space. This chapter introduces the conceptual basis of scan statistics and illustrates how scan statistics can be applied to Irish road traffic collision data. Section 3.1 describes current temporal and spatial scan statistics applicable to collision data and also identifies limitations associated with each method. Section 3.2 gives details of the approach developed to overcome limitations while maintaining strengths of existing methods.

In order to illustrate how scan statistics can be applicable to collision data and to provide the reader with the knowledge required to clearly comprehend issues encountered and results obtained from the analysis, sections 3.3 -3.2.1 provide an overview of the Irish road network, road traffic collision data set and preparatory steps required before scan statistics can be implemented. Section 3.5 gives an overview of the analysis performed in this research.

3.1 Scan Statistics

Scan statistics identify clusters of events by analysing spatial, temporal and space-time data. Clusters can be classified into three groups: temporal clustering; spatial clustering or space-time clustering [228]

- Temporal clustering
  - determines if events are closely located to each other in time;

- Spatial clustering
  - determines if events are closely located to each other in space;
- Space-time clustering
  - determines if events that are closely located to each other in space are also close in time;

With the development of high-speed computers and software scan statistics have risen to prominence in the field of applied probability and statistics[220]. Scan statistics can be defined for discrete or continuous data in the one-dimensional and multi-dimensional case. Sub-sections 3.1.1-3.1.3 outline the background of the scan statistics that are used in this thesis to identify road traffic collision hot spots. A detailed description of methods and applications of scan statistics is given by Glaz and Balakrishnan [229]

3.1.1 Naus' Scan Statistic for point data

In 1965 Joseph Naus [219] proposed the scan statistic to test for temporal clustering for individual time point data. The method involves "scanning" the point data with a scanning window of fixed size in the time period to identify the maximal number of point events within the scanning window. Due to the computational complexity of finding analytical results concerning statistical significance many studies have concentrated on finding approximations and when possible tabulating the tail probabilities [228].

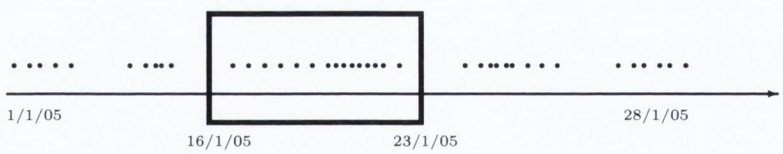

Figure 3.1: Scanning events with fixed length scanning window

With specific reference to road traffic collisions: Let $x_1, x_2, ..., x_N$ be a sequence of independent road traffic collisions and let $t_1, t_2, ..., t_N$ be the date or time corresponding to

each collision. The distance between the i^{th} and j^{th} time points is defined as $d_{ij} = |t_i - t_j|$. The test statistic S_d, the maximum number of cases observed in any interval of fixed length d, is found by scanning all intervals of length d, known as the scanning window of fixed size d, in the time period. Figure 3.1 shows a graphical representation of the scan statistic. Each point on the line represents a road traffic collision. The rectangular box represents a window scanning the data. This window moves along the time line and the number of collisions within each window is recorded. The maximum number of collisions is then assessed. The Null hypothesis states that these collisions are uniformly distributed across the unit interval against the alternative hypothesis of a departure from uniformity.

Collision data $(t_1, t_2, ..., t_n)$ are available over a specified study period $[0, T]$, thus the null hypothesis states that these collisions are uniformly distributed across the unit interval i.e. $H_o : (z_1, z_2, ...z_n)$ are uniformly distributed across $(0, 1]$ interval where $z_i = t_i/T$ for $i = 1, 2, ..., n$.

The test statistic S_d is the maximum number of collisions observed in an interval of fixed length d. The null distribution of S_d is of the form:

$$PrS_d \geq k|n, T = PrS_d \geq k|(t_1, t_2, ..., t_n) \sim Uniform(0, T) \tag{3.1}$$

where $k = k(a, d)$ is the number of collisions in the window $(a, a + d]$.

Neff and Naus [230] published probability tables to evaluate the probability of a cluster for sample sizes of 25 observations. In 1987, Wallenstein & Neff [231] proposed an approximation for the distribution of the scan statistic to enable researchers to analyse larger sample sizes by utilizing binomial probability density and binomial cumulative functions.

$$PrS_d \geq k|n, T \approx ((k/w) - n - 1)b(k|n, w) + 2\sum_{i=k+1}^{n} b(i|n, w) \tag{3.2}$$

where $w = d/T$ and

$$b(i|n, w) = \binom{n}{i} w^i(1 - w)^{n-i} \tag{3.3}$$

The Binomial distribution b (equation 3.3) gives the probability of i successes out of a total of n events, where the probability of success is w. The cumulative sum of probabilities is calculated in the latter section of equation 3.2 i.e. $2\sum_{i=k+1}^{n} b(i|n, w)$ where i represents the number of successes, n is the total number of events and w represents the window width as a portion of time. The approximation (equation 3.2) is exact when the number of successes is greater than the total number of events divided by two, and

provides accurate results otherwise.

As part of the research conducted in this study, Naus' scan statistic was applied to Irish road traffic collision data recorded from 2005-2009. Thus temporal clusters of fatal/serious collisions for varying window widths (1, 7 and 28 days) were identified. Results are given in Chapter 4, section 4.2, p.4.2. The fixed window size choosen in Naus' scan statistic is not subjective thus high-lighting a limitation of this method. Additionally, this approach only identifies the most likely cluster, it does not identify multiple clusters.

3.1.2 Nagarwalla's Variable Window Scan Statistic for Point Data

In 1996 Nagarwalla [221] proposed a variable window scan statistic for point data (i.e. the window did not require a pre-specified fixed value) to determine if events are closely located to each other in time. This scan statistic detects the most likely hot-spot cluster and evaluates the significance of this cluster [228].

Figure 3.2 shows a graphical representation of the variable window scan statistic. Each point on the line represents a road traffic collision. The rectangular boxes represent a variable window scanning the data. This window moves along the time line and the number of collisions within each window is recorded. The maximum number of collisions is then assessed. The Null hypothesis states that these collisions are uniformly distributed across the unit interval against the alternative hypothesis of a departure from uniformity.

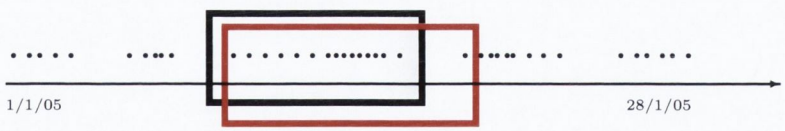

Figure 3.2: Scanning events with variable length scanning window

Let $z_1, z_2, ..., z_n$, $z_i = 1/T$, denote a random sample of n points from the density $f(t)$, which expresses a 'hot spot' cluster on a line:

$$f(n) = \begin{cases} \frac{1}{T} + \delta & \text{for } a \leq t \leq a + d \\ \frac{1}{T} - \delta \frac{d}{T-d} & \text{for } 0 \leq t < a \text{ or } a + d < t \leq 1 \end{cases} \tag{3.4}$$

This result is due to Naus [219], where d is a known constant ($0 < d < 1$), *delta* and a are unknown parameters. For the test hypothesis the null hypothesis and alternative hypothesis are given as $H_0 : \delta = 0$ and $H_1 : \delta > 0$.

Nagarwalla's scan statistic is the maximised likelihood ratio test statistic λ that allows for clusters of variable width d:

$$\lambda = sup_{d,k \geq n_0} \left(\frac{k}{n} \right)^k \left(\frac{n-k}{n} \right)^{n-k} \left(\frac{T}{d} \right)^k \left(\frac{T}{T-d} \right)^{n-k} \tag{3.5}$$

where $k = k(a, d)$ is the number of points in the scanning window $(a, a + d]$ and n_0 is a pre-determined lowest number of cases for clusters. Specifically:

k = number of points in scanning window

n = total number of points

$n - k$ = number of points outside window

$T = 1$

d = distance in scanning window

$T - d$ = distance outside scanning window

Since it is not possible to obtain the null distribution of λ analytically, Monte Carlo hypothesis testing is used to estimate the p-value. Following the calculation of the test statistic is calculated, the same test statistic is calculated for a large number of data sets (e.g. 9999) simulated independently under the null hypothesis of no clustering. A Monte Carlo estimate of the upper tail p-value is given by the proportion of test statistic values based on simulated data exceeding the observed value of the test statistic. A Monte Carlo estimate of the lower tail p-value is calculated in a similar manner [228].

Chapter 4 outlines the results of running Nagarwalla's variable window scan to identify road traffic collision hot spots on National Primary and National Secondary routes in the Republic of Ireland. The variable window gives a distinct advantage over Naus' fixed window scan statistic, however similar to Naus' method this approach only identifies the most likely cluster, it does not identify multiple clusters.

3.1.3 Linear Semantic Scan Statistic

Janeja and Atluri [205] proposed a linear semantic scan statistic (LS^3) technique to identify anomalous windows on a linear path within a semantic segment.

Definition A *linear path* L is defined as a set of one-dimensional spatial locations called markers $M = m_1, m_2, ..., m_n$ such that each marker m_i is associated with a number of attributes $A_i = SA_i \cup BA_i$, where $SA_i = sa_{i1}, sa_{i2}, ...sa_{ip}$ denote the set of structural attributes e.g. highway ID, State ID or type of highway and $BA_i = ba_{i1}, ba_{i2}, ...ba_{ip}$ represent the set of behavioural attributes e.g. number of collisions, number of injuries or number of pedestrian fatalities*

The LS^3 technique consists of three steps: semantic segmentation; computation of scan statistic and window identification†

Definition *Semantic segmentation* S is defined as a set of markers $S \subseteq M$ such that for any two markers $m_i, m_j \in S$, where m_i, m_j are structurally similar.

Structural similarity between markers as for example roads of similar classification - national primary roads etc. can checked using e.g. the Jaccard coefficient (JC) for binary valued attributes. Structural attributes that are binary valued variables show a presence or absence of a structural feature or occurrence or non-occurrence of an event (0 or 1), the JC computes the similarity between the two structural attribute vectors [205] $JC = positive - match/(positive - match + positive - mismatch)$.

The linear scan statistic is used to identify anomalous scan windows $w = [m_i, m_j]$ of the linear path by aggregating the behavioral attributes associated with the markers within the semantic segments as for example running the scan to identify anomalies of road traffic collisions along a road network starting at the beginning of a particular road (N7) and finishing at the end of the road (N7). In this case, the road traffic collisions constitute the behavioural attributes and the beginning/end of the road constitutes the markers. The test statistic λ is computed for the behavioral attribute (e.g. number of collisions) to identify anomalous windows for that attribute value. λ is computed for windows varying from all marker locations and subsequently the maximum λ from all of the windows is identified. Monte Carlo hypothesis testing is used to estimate the p-value and validate results obtained.

Definition Given a semantic segment S, a set of markers M, a scan window w in S, and a significant behavioral attribute ba^s, the *test statistic* λ is defined as:

*The term 'behavioural attribute' may seem unusual in defining the number of highway collisions or injuries, however in the desire to maintain consistency with original research the terminology will remain unchanged from the terminology used in the original research paper.

†Janeja and Atluri [205] assume a linear path is comprised of one-dimensional spatial locations called markers, where a set of structural and behavioural attributes are associated with each marker. The linear path is divided into linear semantic segments where each semantic segment contains markers associated with similar structural attributes. Scan statistics are used to identify the windows within a semantic segment whose behavioural attributes are anomalous.

$$\lambda = \frac{(x_w/d_w)}{(x_{-w}/d_{-w})} \tag{3.6}$$

where:

x_w is the value of the ba^s for the markers within the scan window;

x_{-w} is the value of the ba^s for the markers outside the scan window;

d_w is the physical distance between the one dimensional marker locations in the scan window;

d_{-w} is the physical distance between the one dimensional marker locations outside the scan window;

The LS^3 approach (as defined above), does not address the issue of multiple linear intersecting paths, thus a recent article by Shi and Janeja [207] examined the identification of anomalous windows on linear intersecting paths - scan statistics for linear intersecting paths ($SSLIP$).

Chapter 4, section 4.7 outlines the results of running the scan statistics with semantic segmentation to identify road traffic collision hot spots on National Secondary routes in the Republic of Ireland. Section 4.7.4 reports results of using semantic segmentation to identify road collision hot spots within specific speed limit zones (e.g. sections of road with a speed limit of 50km/h or 60km/h etc.) The LS^3 approach only identifies the most likely cluster within each semantic segment, it does not identify multiple clusters.

3.1.4 Scan Statistics for Linear Intersecting Paths

The scan statistic for linear intersecting paths $SSLIP$ technique involves three steps. Initially a subset of intersecting paths are identified, routes are traversed to identify varying size directional windows along paths and Monte Carlo simulations were used to validate results that the identified window was truly anomalous. Three variations of the $SSLIP$ are discussed by Shi and Janeja [207] which identify anomalous windows based on directional linear windows, starting from intersections on cross paths and identification of anomalous windows in a purely combinatorial process.

Traversing a route can be explained using the Red Cow interchange as an example.*

*The underlying concepts of traversing a route may also be explained using the unit circle, see appendix for details.

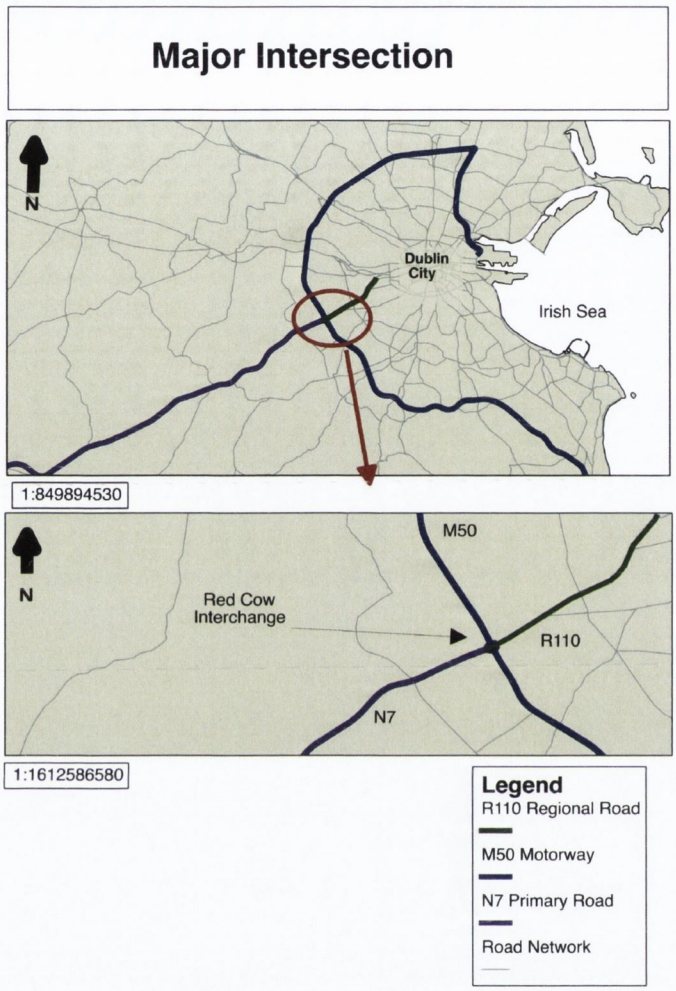

Figure 3.3: Red Cow Interchange

The Red Cow interchange is a major intersection which carries large volumes of traffic. This intersection is located in Co. Dublin and links the N7 (Limerick-Dublin) national primary road to the M50 motorway and the R110 regional road (Naas Road). The M50 motorway is divided by a median strip/barrier to separate traffic travelling in a north/south-bound direction (similarly the N7 national primary road separates traffic travelling in an east/west-bound direction). The N7 and the M50 intersect at the Red Cow interchange. A person travelling on the N7 from Limerick (in the west) to Belfast

(in the north) will not travel on the same section of road as a person travelling from Belfast to Limerick because both the M50 and N7 contain median strips/barriers. There are twelve different combinations of directional travel along the M50/N7 roads, these combinations are outlined in the following table:

Table 3.1: Combinations

Combination	Direction on route
	start in the west:
1	travel east towards Dublin on N7 for full journey
2	travel east towards Dublin on N7 then travel north towards Belfast on M50
3	travel east towards Dublin on N7 then travel south towards Wexford on M50
	start in the east:
4	travel west towards Limerick on N7 for full journey
5	travel west towards Limerick on N7 then travel north towards Belfast on M50
6	travel west towards Limerick on N7 then travel south towards Wexford on M50
	start in the north:
7	travel south towards Wexford on M50 for full journey
8	travel south towards Wexford on M50 then travel east towards Dublin on N7
9	travel south towards Wexford on M50 then travel west towards Limerick on N7
	start in the south:
10	travel north towards Belfast on M50 for full journey
11	travel north towards Belfast on M50 then travel east towards Dublin on N7
12	travel north towards Belfast on M50 then travel west towards Limerick on N7

After traversing the N7 and M50 routes via the Red Cow interchange, the linear scan statistic (as defined in equation 3.6) could be used to identify anomalous windows with respect to direction of traffic flow. The largest linear scan statistic would be identified as the anomalous window and Monte Carlo simulations could be used to validate this result. Unfortunately, this combinatorial approach cannot be applied to Irish road traffic collision data as the travelling direction of vehicles is not recorded in the database (e.g if a collision occurs on the M50, it is unknown if the collision occurred on the north-bound lane or on the south-bound lane).

Chapter 4, section 4.9 gives results from applying scan statistics to a known speed collision zone (as designated by An Garda Síochána) occurring on a regional road which incorporates an intersection. This intersection links two regional roads in a rural town (these roads do not have median strips/barriers separating traffic into directional lanes e.g. north-bound or south-bound).

3.1.5 Scan Statistics using SaTScan

SaTScan software is open-source software which was developed by Martin Kulldorff and Information Services to analyse temporal, spatial and space-time data [232].

Bernoulli Model

The temporal scan statistic uses a window that moves in one dimension (e.g. time). and can be used to detect and evaluate the most likely hot spot cluster within the study interval divided into several disjoint subintervals [228]. The Bernoulli model [233, 194] can be applied to temporal case-control data. The likelihood function for the Bernoulli model is:

$$\left(\frac{c}{n}\right)^{c}\left(\frac{n-c}{n}\right)^{n-c}\left(\frac{C-c}{N-n}\right)^{C}-c\left(\frac{(N-n)-(C-c)}{N-n}\right)^{(N-n)-(C-c)}I() \tag{3.7}$$

where C is the total number of cases; c is the observed number of cases within the window; n is the total number of cases and controls within the window and N is the combined total number of cases and controls in the data set. $I() = 1$ when the window has more cases than expected under the null hypothesis and 0 otherwise (- the null hypothesis states that the collision times are uniformly distributed across the unit interval).

The likelihood function is maximised over all window locations and sizes and the one with the maximum likelihood cluster constitutes the most likely cluster. The likelihood ratio for this window constitutes the maximum likelihood ratio test statistic [232]. Monte Carlo hypothesis testing is used to obtain the null distribution of test statistic and Monte Carlo simulated p-value.

With reference to Irish collision data, Bernoulli models were applied to road traffic collisions recorded from 2005-2009 in Irish cities: Dublin, Cork, Limerick, Galway and Waterford. In these models, fatal/serious collisions and minor collisions denoted 'cases' and 'controls' respectively. Varying window widths of 7 days and 28 days were used in these models. Chapter 4 section 4.3 reports the results from this analysis.

3.1.6 Space-Time Scan Statistics

Kulldorff [234] developed the Space-Time permutation model. The space-time scan statistic is defined by a "cylindrical window with a circular (or elliptic) geographic base with height corresponding to time. The base is defined exactly as for the purely spatial scan statistic, while the height reflects the time period of potential clusters. The cylindrical window is then moved in space and time, so that for each possible geographic location and size, it also visits each time period" [232]

The likelihood function for the space-time permutation model is:

$$\left(\frac{c}{E[c]} \right)^{c} \left(\frac{C-c}{C-E[c]} \right)^{C-c} I() \tag{3.8}$$

where C is the total number of cases; c is the observed number of cases within the window; $E[c]$ is the covariate adjusted expected number of cases within the window under the null hypothesis. $I() = 1$ when the window has more cases than expected under the null hypothesis ans 0 otherwise.

As above, the likelihood function is maximised over all window locations and sizes and the one with the maximum likelihood cluster constitutes the most likely cluster. The likelihood ratio for this window constitutes the maximum likelihood ratio test statistic [232]. Monte Carlo hypothesis testing is used to obtain the null distribution of test statistic and Monte Carlo simulated p-value.

Similar to the data used in the Bernoulli models, space time permutation models were applied to road traffic collisions recorded from 2005-2009 in Irish cities: Dublin, Cork, Limerick, Galway and Waterford. The geographical co-ordinates of each collision are recorded in the collision data base, thus enabling the spatial aspect of the data to be exploited. Varying window widths of 7 days and 28 days were used in space time permutation models. Chapter 4 section 4.4 reports the results from these models. The main disadvantage of Kulldorff's approach is the use of a circular or cylindrical window to identify hot spots, as parallel or nearby roads may be considered together e.g. a regional road in close proximity to a national primary road would be considered together, however these roads are structurally different (see section3.3, p.3.3 for description of Irish road network).

3.2 Systematic Approach

Despite the numerous methods in existence to identify hot spots, these approaches are not without limitations. Kulldorff's space-time scan statistic cannot identify a hot spots on individual roads because the circular or cylindrical window is not restricted to an individual road. Naus' fixed window temporal scan statistic and Nagarwalla's variable window temporal scan statistic were originally developed to detect hot spots over time, they cannot identify the spatial location of hot spots and do not identify multiple hot spots occurring on along a road.

This research identifies hot spots by refining the temporal scan statistic and utilizing the underlying concept of Nagarwalla's variable window scan statistic. This research adapts distance (km) along a linear network (road) as distinct from distance (days) in (linear) time (see figure3.4). Taking this approach overcomes the issue of identifying the

spatial location of a hot spot and can be easily implemented on national primary roads.

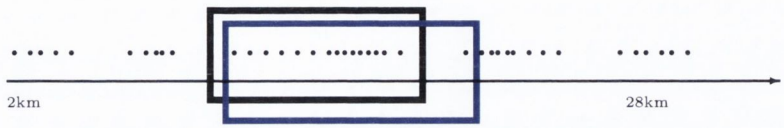

Figure 3.4: Scanning events with variable length scanning window

This research develops a systematic approach to identify multiple clusters along a linear network. Section 3.2.1 outlines the initial preparatory steps required before the scan statistic could be run on the data. A number of possible approaches were taken into consideration to identify multiple clusters along the road network:

- Adapted variable window scan statistic, as described above, was used to identify most likely cluster (based on maximum lambda value).
- Adapted and refined variable window scan statistic, was expanded to identify multiple clusters by:
  - examining all significant clusters (spanning any distance e.g. a cluster of 10km in length) according to their location on the road - starting at the beginning of the road and finishing at the end of the road
  - examining all significant clusters (with spanning distance restricted to $< 5km$ (denoting collision corridors) and $< 500m$ (denoting collision hot spots)) according to their location on the road - starting at the beginning of the road and finishing at the end of the road
  - extracting to most likely cluster (based on maximum lambda value) then extend this approach by examining remaining significant clusters and extracting the next most significant cluster that does not overlap the first identified cluster (see figures 4.3-3.6) and select this cluster (based on its maximum lambda value). This process is repeated until there are no further clusters

Figure 3.5: Overlapping

Figure 3.6: Non-overlapping

3.2.1 Preparatory Steps

Before the scan statistic was run on the collision data, several steps of preparation were required. Initially the road network map and collision data were loaded into open source map reading software QGIS/GRASS. The steps below provide a brief outline of the preparatory steps required, a more detailed description of each step is given in the appendix .4.

The following GIS steps, indicated below, were repeated for each individual national primary and secondary route. Certain routes had to be split into different parts because the route was intersected by another route for distances greater than 100 meters (e.g. N52 national secondary road which runs from Nenagh, Co. Tipperary to Dundalk, Co. Louth (see results p.4.7.2).

- Clean each individual route (i.e. eliminate gaps in the road)
- Snap collisions (within 100m) to the individual route (as before the use of geo-referencing devices co-ordinates were manually taken with paper maps which sometimes lead to inaccuracies in grid reference locations).
- Calculate the distance of each collision from the geographical co-ordinates at the beginning of the route e.g. the N7 runs from Limerick to Dublin, thus the beginning of this road can be designated as Limerick or Dublin (the same results are produced in both cases).
- Divide the calculated distance by the total length of the road
- Load this data in statistical software R and run the scan statistic

After completing the scan statistic runs for all of the collisions on each national primary and secondary routes, this resulted in a list of road traffic collision hot spots for each route. An electronic map was prepared in QGIS, high-lighting the identified collision hot spots and corridors.

3.3 Road Network

The Irish road network consists of roads classified as motorway, national primary roads, national secondary roads, regional roads and local roads. The four road types are:

- National Primary Roads
  - major long distance through roads linking the principal ports or airports, cities and large towns
- National Secondary Roads
  - medium distance through roads connecting important towns and linking up to the national primary roads
- Regional Roads
  - provide the main links between national roads
- Local Roads
  - include all other urban and rural roads

Motorways are denoted by the letter 'M' followed by one or two digits which give reference to a particular national road or regional road or part of it which is a motorway. National roads are denoted by the letter 'N' followed by one or two digits which give reference to a particular national road. Similarly, regional roads are denoted by the letter 'R' followed by 1-3 digits which indicate a particular regional road and local roads are denoted by the letter 'L' followed by 1-4 digits. All Irish public roads have a designated speed limit, and if no speed limit sign is present then the default speed limit applies. Since January 2005 speed limits in Ireland have been displayed in kilometers per hour (km/h) as opposed to miles per hour (mph) Table 3.2 displays the default speed limits for different roads under the Road Traffic Act 2004. These default speed limits can be changed on a permanent basis by city and county councils (as previously outlined in section 2.1.2).

Table 3.2: Default Speed Limits

Type of Road	Speed Limit
Motorway	120km/h
National roads (primary and secondary)	100km/h
Non-national roads (regional and local)	80 km/h
Roads in built-up areas (cities, towns and boroughs)	50 km/h

3.4 Data

An electronic version of the Irish road network and road traffic collision data was aquired for analysis in this study. Electronic Geographic Information Systems (GIS) maps of the national primary and secondary routes in the Republic of Ireland were supplied by the National Roads Authority (NRA). Road traffic collision data were obtained from an electronic collision database held by the Road Safety Authority (RSA). This database records the geo-location of the collision, and a very extensive list of relevant characteristics including details on all individuals, road conditions, weather conditions etc. for the years 1996–2009. These data refer to all police reported road collisions with casualties. Detailed records for damage only collision data is not normally retained in the Republic of Ireland thus this research was restricted to injury collisions only.

3.4.1 Focused Models: Scan Statistics

For the purposes of the identification of road traffic collision hot spots and corridors data were restricted to reduced time periods (2005-2009) due to the desire to produce meaningful and up-to-date results, as many advancements in technology/road infrastructure have occurred since 1996 (see chapter 4 section 4.1) for overview of the data used to identify road collision hot spots and corridors). The original intention of this research was to identify collisions hot spots and corridors on the whole road network in the Republic of Ireland, however, unfortunately, this was not possible because of limitations in both the road traffic collision data set and the electronic Irish road network maps.

Currently, road numbers for regional/local roads are not recorded in the collision database and before the use of a geographical positioning system (GPS) device (e.g. Garmin, TomTom, SatNav) to record the co-ordinates of a collision location the Garda at the scene of a collision recorded the collision co-ordinates manually with paper maps, which sometimes lead to inaccuracies in grid reference locations. There are no electronic maps with labelled regional/local roads available for the Republic of Ireland and vector maps provided by the Ordinance Survey do not contain regional/local road number attribute data,thus regional roads that were examined in this study were extracted from electronic maps by tracing the route from paper Ordinance Survey maps.

Electronic maps containing speed limit zones* for each road are not available for the whole road network. The National Roads Authority (NRA) have maps containing speed limit zones for some national roads, however not all speed zones are kept up-to-date,

*A speed limit zone denotes a section of road with a particular speed limit e.g. zone 1 could denote a section of road with a 50km/h speed limit and this zone spans a distance of 10km, zone 2 could denote a section of road with a 60km/h speed limit and this zone spans a distance of 500m etc.

thus as a result identification of hot spots within speed limit zones on the N81 national secondary road in this research required manually recording speed limit zone co-ordinates via a 'GPS' device (e.g. Tom Tom) and travelling the road beginning in Dublin City to the end of the road outside of Tullow Co. Carlow.

Directional data (i.e. the direction of travel for each vehicle involved in the collision) is not recorded in the collision data base thus it impossible to distinguish which direction the collisions occurred thus leading to difficulty in identifying the location of collision hot spots/corridors e.g. as mentioned in section 3.1.4, p.46 this is of vital importance as collisions occurring in the north-bound lane of the M50 motorway should not be combined with collisions occurring on the south-bound lane. Thus without the recording of directional data for collisions occurring on motorways/dual carriage-ways (where lanes are separated by a median strip or barrier) the application of scan statistics to identify collision hot spots/corridors is unrealistic e.g. as combining collisions from north-bound & south-bound lanes on the M50 will increase collision count thus artificially creating a significant cluster.

3.4.2 Global Models: Regression Models

Based on best practice recommendations [162], the original intention of this research was to apply hierarchical Bayesian regression models to road traffic collision data, however, unfortunately due to poor quality data this could not be achieved. Age and sex of both drivers and passengers in collisions involving 3 or more vehicles and collisions involving pedestrians (where 3 or more pedestrians were involved) are currently not recorded in the road collision database and as mentioned above, road numbers for regional and local roads are also not recorded in the database, thus preventing the development of hierarchical models (of injuries nested within collisions nested within route). In addition to the lack of data injury and location data there were a large number of variables in the data set that contained missing values as for example road markings, weather, seatbelt, drivers license (learners permit or full drivers license). For the purpose of the regression models for single vehicle and multi-vehicle collision, complete data (with no missing values) were used in the analysis, Chapter 5, section 5.1 gives an overview of the data set used in the regression models. In order to ascertain the characteristics associated with different types of road traffic collision injuries regression models were developed for single vehicle and multi-vehicle collisions recorded between 2004-2008 (inclusive) and 2009 collision data were used as test data to evaluate these regression models.

3.4.3 Software

Data were analysed using the statistical software packages JMP (version 7, 2007; SAS Corp) for data management, R (version 2.13.0, R CORE TEAM; 2011) for statistical analysis and scan statistics. QGIS/GRASS (version 1.4.0; 2010) was used for geographical information software (GIS) and SaTScan (version 9.1.1; 2011) was used for Bernoulli and Space-Time permutation models.

3.5 Scope of Analyses

As outlined in chapter 1, section 1.2 the main aims of this research is to develop and deploy the required efficient statistical methodology for identifying road traffic collision hot spots/corridors along the road network in Ireland and to assess the human, environmental and infrastructural factors associated with fatal/serious road traffic collision injuries. The scope of analyses in this research is based on two thematic approaches:

- Focused models (scan statistics) to identify road collision hot spots/corridors
- Global models (regression models) for road traffic collisions classified by type

3.5.1 Focused Models: Scan Statistics

Scan statistics were implemented on road traffic collision data recorded from 2005-2009.

- Naus' fixed window temporal scan statistic
  - run on all fatal/serious Irish road traffic collision data. Window widths of 1, 7 and 28 days were implemented.
- Kulldorff's Bernoulli model
  - run on all fatal/serious (cases) and minor (controls) road traffic collisions in cities- Dublin, Cork, Limerick , Galway and Waterford. Window widths of 7 and 28 days were implemented.
- Kulldorff's Space-Time Permutation model
  - run on all road traffic collisions in cities- Dublin, Cork, Limerick , Galway and Waterford. Window widths of 7 and 28 days were implemented.
- Adapted and refined variable window scan statistic
  - run on all road traffic collisions on individual national primary routes.

- Adapted and refined variable window scan statistic with semantic segmentation
  - run on road traffic collisions occurring on sections of individual national secondary routes
  - run on road traffic collisions occurring in speed limit zones on the N81 national secondary route
- Adapted and refined variable window scan statistic with semantic segmentation for linear intersecting paths
  - run on collisions occurring at a known speed collision zone (as designated by An Garda Síochána) occurring on a regional road which incorporates an intersection.

3.5.2 General Models: Regression Models

Regression models were developed to examine the human, environmental and infrastructural factors associated with fatal/serious single vehicle and multi-vehicle collision injuries in the Republic of Ireland*. As mentioned in section 3.4.2 regression models were developed from a Bayesian perspective thus following best practice recommendations, however due to data limitation it must be noted that the Bayesian models developed in this research produce the exact same results as frequentist models because non-informative priors have been used in the Bayesian models. Regression models were developed using road traffic collision data recorded from 2004-2008 and collision data recorded in 2009 were used to evaluate these regression models.

- Single vehicle collisions
  - Binomial regression model - focused on the counts of all fatal/serious injuries as a proportion of all persons involved in a single vehicle collision.
  - Logistic regression model was applied to a subset of the data - 'driver-only' i.e. the driver was the only occupant of the vehicle involved in the single vehicle collision.
- Multi-vehicle collisions
  - Binomial regression model - focused on the counts of all fatal/serious injuries as a proportion of all persons involved in multi-vehicle collisions.

*Single vehicle collision denotes a collision involving one vehicle and multi-vehicle collision denotes a collision involving two or more vehicles

Chapter 4

Scan Statistics Results

Between 2005 and 2009, 31,369 road traffic collisions which resulted in at least one fatal/serious/minor injury were recorded in the Republic of Ireland. Section 4.1 gives a descriptive overview of the data used in the identification of collision hot spots and corridors. The remainder of this chapter reports the results obtained from the application of scan statistics to these road traffic collisions. Initially results from Naus' fixed window temporal scan statistic (applied to all fatal/serious road traffic collision in Ireland) shall be discussed. Sections 4.3 and 4.4 will report findings from the application of the Bernoulli model and space-time permutation models to road traffic collisions recorded in the cities of Dublin, Cork, Limerick Waterford and Galway. Section 4.5-4.6 shows results of refining Nagarwalla's variable window scan statistic to road traffic collisions which have occurred on national primary routes to identify collision hot spots/corridors. Sections 4.7 - 4.8 provides the results obtained from semantic segmentation (defined by road sections bounded by national road intersections) of national secondary roads (N51-N87), regional roads (R423 & R402) and segmentation of national primary road (N81) based on speed limit areas. Additionally, results from an examination of a known speed collision zone (as designated by An Garda Síochána) occurring on a regional road which incorporates an intersection are outlined in section 4.9. Finally, section 4.10 provides a summary of results given in this chapter.

4.1 Data Overview

As previously mentioned, data used for the identification of hot spots and corridors were restricted to reduced time periods (2005-2009) due to the desire to produce meaningful and up-to-date results. Approximately 78% (23,141/31,369) of all collisions recoded between 2005-2009 (inclusive) occurred on regional/local roads, 17% (5,374/31,369) occurred on national primary roads and 9% (2,854/31,369) occurred on national secondary

roads over the same time period. The original intention of this research was to identify collisions hot spots and corridors on all national primary, secondary, regional and local roads in the Republic of Ireland, however, unfortunately, as discussed in chapter 3, section3.4 this was not possible because of limitations in both the road traffic collision data set and the electronic Irish road network maps.

Table 4.1: Road Collision Data 2005-2009

	Primary Roads (%)	Secondary Roads (%)	Regional/Local Roads (%)
Total Collision Count	5374	2854	23141
Collision Type			
Pedestrian	481 (9.0%)	275 (9.6%)	4161 (18.0%)
Single Vehicle	1153 (21.5%)	753 (26.4%)	5143 (22.2%)
Head-on	792 (14.7%)	569 (19.9%)	3785 (16.4%)
Angle	734 (13.7%)	337 (11.8%)	2979 (12.9%)
Rear-end	1340 (24.9%)	469 (16.4%)	2946 (12.7%)
Unknown	874 (16.3%)	451 (15.9%)	4127 (17.8%)
Light			
Hours of daylight	790 (14.7%)	528 (18.5%)	2805 (12.1%)
Hours of darkness	4484 (83.4%)	2270 (79.5%)	19788 (85.5%)
Unknown	100 (1.9%)	56 (2.0%)	548 (2.4%)
Day			
Weekday	3734 (69.5%)	1932 (68.7%)	15962 (69.0%)
Weekend	1492 (27.8%)	803 (28.1%)	6572 (28.3%)
Bank holiday weekend	146 (2.7%)	89 (3.1%)	607 (2.6%)
Road Surface			
Dry	3037 (56.5%)	1536 (53.8%)	13370 (57.8%)
Wet	1977 (36.8%)	1135 (39.8%)	8076 (34.9%)
Other/Unknown	360 (6.7%)	183 (6.4%)	1695 (7.3%)
Junction			
No	3878 (72.2%)	2142 (75.1%)	16439 (71.0%)
Yes	1496 (27.8%)	712 (24.9%)	6702 (29.0%)
Speed Limit			
50km/h	1215 (22.6%)	599 (21.0%)	11440 (49.4%)
60km/h	394 (7.33%)	147 (5.2%)	1477 (6.4%)
80km/h	347 (6.5%)	250 (8.8%)	9307 (40.2%)
100km/h	3090 (57.5%)	1858 (65.0%)	917 (4.0%)
120km/h	328 (6.1%)	0	0
Personal Injury Count			
Fatal	502	214	942
Serious	898	496	2868
Minor	6868	3373	28760
Not Injured/Unknown	526	220	790

Approximately 67% (21146/31,369) of all collisions recorded on the Irish road network occur on a dry road surface and 85% (26,542/31,369) occur during the hours of darkness* Examination of Table 4.1 indicates the most frequently recorded collision type occurring on national primary roads is rear-end collisions, which account for approximately 25% (1,340/5,374) of all recorded collisions on national primary roads. In comparison to the most frequently occurring collision occurring on national secondary and regional/local roads - single vehicle collisions which account for approximately 26% (753/2,854) and 22% (5,143/23,141) of collisions respectively. These figures must be considered with caution as there was a large proportion (16-20%) of collisions that were 'unknown collision type'.

4.2 Naus' Scan Statistic for Point Data

A total of 4,569 fatal/serious road traffic collisions were recorded in the Republic of Ireland from 1st January 2005 - 31st December 2009. As discussed in Chapter 3, section 3.1.1 Joseph Naus [219] proposed the scan statistic to test for temporal clustering for individual time point data. With reference to Irish road traffic collision data, Wallenstein & Neff's approximation was used to identify significant collision clusters over time for different fixed lengths windows of 1, 7, 14 and 28 days. Results in Table 4.2 show that significant clusters were identified beginning at the end of September 2005 and ending in October 2005. The geographical location of these clusters are unknown, thus no obvious explanation on these findings can be given. This highlights a disadvantage of applying Naus' scan statistic to road traffic collision data, as the approach is too global to be informative.

Table 4.2: Wallenstein & Neff's approximation: fatal/serious collisions (2005-2009)

Fixed Length (days) d	Max. cases s_d	Window $\frac{S_d}{1826}$	p-value	Date
1	11	0.001	0.76	18/03/2007
7	43	0.004	¡0.001	29/09/2005 - 5/10/2005
14	69	0.008	¡0.001	26/09/2005 - 9/10/2005
21	94	0.012	¡0.001	27/09/2005 - 17/10/2005
28	115	0.015	¡0.001	29/09/2005 - 26/10/2005

- The test statistic S_d is the maximum number of cases observed in an interval of fixed length d

- Total number of days from 01/01/2005 - 31/12/2009 = 1826 days

*The term 'dark' indicates the hours of darkness which begins 30 minutes after sunset and ends 30 minutes before sunrise. [235]

4.3 Bernoulli Model

A retrospective temporal analysis using the Bernoulli model (as outlined in chapter 3, section 3.1.5, p.48) was applied to all road traffic collisions recorded from 1st January 2005 - 31st December 2009 for each of the cities in Ireland: Dublin, Cork, Limerick, Waterford and Galway. Fatal/serious road traffic collisions were denoted as cases and minor collisions were denoted as controls. Total number of collisions recorded denotes the sum of fatal, serious and minor collisions. The Bernoulli model output for each city individually (as opposed a Bernoulli model of all fatal/serious collisions (cases) and minor (controls) in Ireland), provides more informative results* Tables 4.3-4.4 below show results obtained for the most likely cluster for Cork City and Galway City for the period 1st January 2005 - 31st December 2009. There was insufficient evidence to suggest that there was a significant temporal cluster in:

- Dublin City (Total of 3,628 collisions recorded; 8.7% (314/3628) were fatal/serious collisions)
- Limerick City (Total of 557 collisions recorded; 5.8% (32/557) were fatal/serious collisions)
- Waterford City (Total of 306 collisions recorded; 7.2% (22/306) were fatal/serious collisions).

Detailed results for cities of Dublin, Limerick and Waterford can be seen in Appendix .5, p.187.

4.3.1 Cork City

A total of 905 road traffic collisions were recorded in Cork City. Approximately 7% (61/905) of these collisions were fatal/serious collisions. Table 4.3 shows the results of the most likely cluster for Cork City. This cluster started in June 2005 and ended in November 2006.

*A larger number of collisions naturally occur in cities in comparison to rural areas, thus identifying a collision cluster in each city on a temporal scale would indicate a specific time period where there was a cluster of fatal/serious collisions in that city e.g. A temporal cluster identified in Cork City may be due to an event/festival or a period of road works/construction. However without details of spatial location, identification of temporal clusters is of limited practical use.

Table 4.3: Bernoulli Model: Road Traffic Collisions Cork City (2005-2009)

Output	
Location IDs included	all
Population	254
Number of cases	31
Expected cases	17.12
Observed / expected	1.81
Relative Risk	2.65
Log likelihood ratio	7.57
P-value	0.04
Time frame	10/6/05 - 30/11/06

4.3.2 Galway City

A total of 374 road traffic collisions were recorded in Galway City. Approximately 10% (38/374) of these collisions were fatal/serious collisions. Table 4.4 shows the results of the most likely cluster for Galway City. This cluster started in January 2007 and ended in November 2007.

Table 4.4: Bernoulli Model: Road Traffic Collisions Galway City (2005-2009)

Output	
Location IDs included	all
Population	18
Number of cases	8
Expected cases	1.83
Observed / expected	4.37
Relative Risk	5.27
Log likelihood ratio	7.62
P-value	0.05
Time frame	5/1/07 - 8/11/07

Despite the fact that there was insufficient evidence to suggest a significant cluster in each of these cities, findings indicate that clusters identified (in each city) all began in 2005, however these clusters span large time scales e.g. a significant cluster identified in Cork city begins in April 2005 and ends in December 2006, thus providing time scales of dubious practical value. A possible explanation for large spanning time scales is due to the number of collisions recorded in each city, as there are a number of calendar days where no collisions have been recorded.

Power

The statistical power of scan statistics to detect clusters must be taken into consideration when examining the results obtained for each of the Irish cities. For the Bernoulli model, the statistical power to detect a cluster depends on the total number of cases and the expected number of cases in the cluster under the null hypothesis. The greater the total number of cases, the higher the power to detect the cluster [236]. The Bernoulli models used in this research denote fatal/serious collisions as 'cases' and minor collisions are denoted as 'controls'. As can be seen in the above output (and results in the appendix) the number of fatal/serious collisions are very low in comparison to minor collision counts*

As in the case of the Naus' scan statistic, the Bernoulli model cannot be used to identify the geographical location of these clusters, thus inhibiting explanation of possible causes for these clusters.

4.4 Space Time Permutation Model

As discussed in section 3.1.6 the space time permutation model compares the number of observed cases in a cluster with the number of cases that would have been expected if the spatial and temporal locations of all cases were independent of each other so that there is no space time interaction [232].

A retrospective analysis using the space time permutation model was applied to all road traffic collisions recorded from 1st January 2005 - 31st December 2009 for each of the cities in Ireland: Dublin, Cork, Limerick, Waterford and Galway. Dublin City was the only city that a significant cluster was identified. There were insufficient evidence to suggest that there were significant clusters/secondary clusters in Cork (905 recorded collisions), Limerick (557 recorded collisions), Galway (374 recorded collisions) and Waterford (306 recorded collisions). Detailed results for cities Cork, Limerick, Galway and Waterford can be seen in Appendix .6, p.189.

4.4.1 Dublin City

A total of 3,628 road traffic collisions were recorded in Dublin City. Table 4.5 and figures 4.1 - 4.2 show graphical images of the most likely cluster identified in Dublin city. This cluster was located in Dublin City (St. Stephens Green, Stilorgan, Ranelagh, Harold's Cross) and occurred between January - March 2008. This cluster spans a large

*Applying Bernoulli models to all fatal, serious and minor injury collisions (cases) and material damage collisions (controls) in each city could be a possible solution to low fatal/serious injury collision counts in comparison to minor collision counts for each city if collision data records containing material damage collisions were maintained.

geographical area. Insufficient evidence exist to suggest the presence of a significant secondary cluster in Dublin City.

Table 4.5: Space Time Permutation Model - Dublin City

Output	
Radius	1524.13
Number of cases	57
Expected cases	24.80
Observed / expected	2.30
Test statistic	15.38
P-value	0.01
Time frame	4/1/08 - 27/3/08

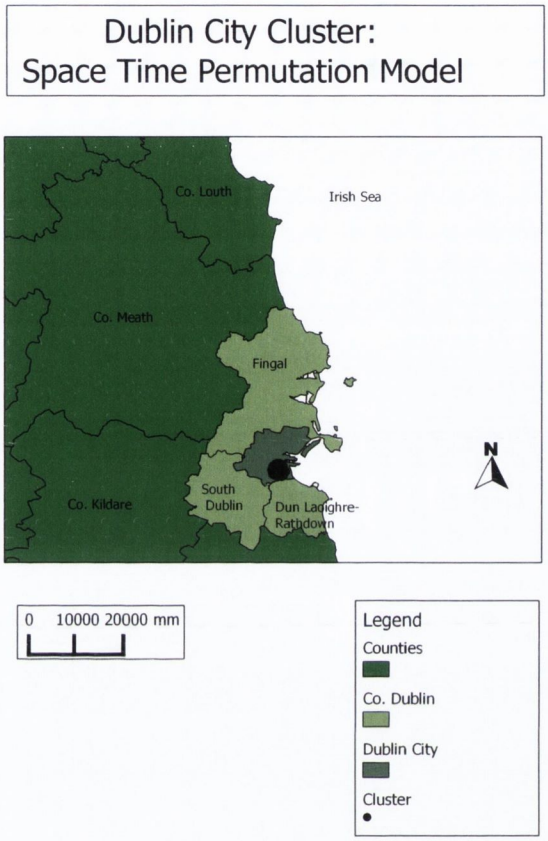

Figure 4.1: Dublin City Cluster: Space Time Permutation Model

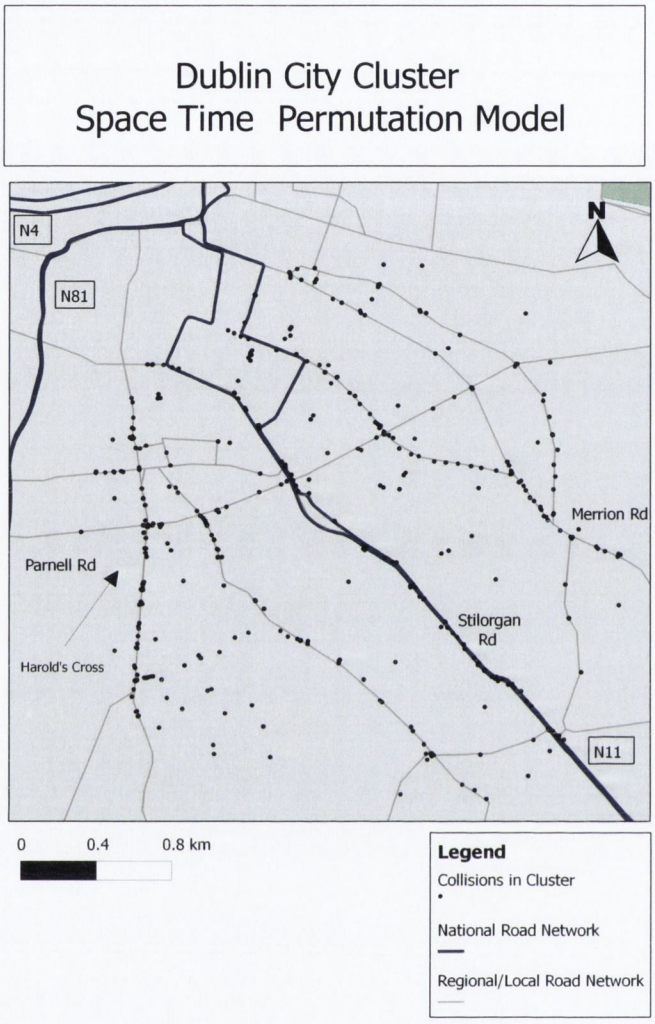

Figure 4.2: Dublin City Cluster: Space Time Permutation Model

Discovery of clusters along individual roads is of particular interest when examining road traffic collisions as collisions occurring on a national primary road (e.g. Stilorgan Rd, Dublin) may have a different pattern than collisions occurring on a regional road (Merrion Rd, Dublin) because national primary roads and regional roads are structurally different. Thus a disadvantage of using space-time models to identify road traffic collision clusters is due to the inability of this approach to restrict clusters to individual roads in the network.

4.5 Nagarwalla's Variable Window Scan Statistic

Nagarwalla's scan statistic was applied to all recorded collisions (from 1/1/2005 - 31/12/2009) on each individual national primary road. As stated in Chapter 3 national primary roads are major long distance through roads linking the principal ports or airports, cities and large towns. There are 34 national primary roads in the Republic of Ireland. Based on Nagarwalla's original work (see equation 3.5, p.44), Table 4.6 shows significant clusters identifed for each road (by using a default minimum of five collisions in the scanning window) and extracting significant clusters* based on the maximum lambda value. Table 4.7 shows the national primary roads where no significant clusters were identified.

Table 4.6: Most likely cluster (max lambda extraction)

Route	Cluster Length	Cluster Size	Cluster Location
M1	1.4km	11	M1/M50 interchange, Dublin
N1	3.0km	56	Swords Rd-Parnell St, Dublin
N2	6.7km	75	North Rd-N2/Upper Dorset St. Jnct, Dublin
N3	183m	15	NW of Blackbull, Co. Meath
N4	14.7km	112	Leixlip Rd-Aston Quay/Westmoreland St. Jnct, Dublin
N5	9.9km	33	W of Cloggernagh East-Bridge St. Westport,Co. Mayo
N6	465m	7	Dun Na Coiribe-Headford Rd, Galway, Co. Galway
N7	43m	7	Newlands Cross, Lucan, South Dublin
N8	6.5km	38	N8/N22 Jnct- NE of Richmond, Co. Cork
N9	63km	95	Mill St, Co. Kilkenny-R705/N9 Jnct Co. Carlow
N10	81m	6	S of Flood Hall-Floodhall, Co. Kilkenny
N11	15km	147	Dublin Rd-Leinster St/Kildare St Jnct, Dublin
N13	732m	9	SW of Moyle-NE of Moyle, Co. Donegal
N15	76m	5	Bundoran Rd, Sligo, Co. Sligo
N16	14.4m	5	Newline-E of Tomrud, Co. Leitrim
N17	191m	8	N17/R331 (Ballydine Rd) Jnct, Co. Mayo
N18	92m	6	Coonagh Roundabout, Limerick, Co. Limerick
N20	16m	5	N20/R518 Jnct, Limerick, Co. Limerick
N21	729m	11	Convent Rd-Bridge St Abbeyfeale, Co. Limerick
N22	689m	14	N72/N22 Jnct-Lissivigeen Rd, Co. Kerry
N24	1.2km	12	Haywood Rd-N24/R689 Jnct, Clonmel, Co. Tipperary
N25	31.7m	99	Bandon Rd Roundabout-E of Ballyedekin, Co. Cork
N30	323m	7	Mill Park Rd-Abbey Sq, Enniscorthy, Co. Wexford
N32	322m	5	Malahide Rd, Dublin
M50	36km	160	SE of Jnct 15 M50- Jnct 1 M50, Dublin

*5% level of statistical significance

Table 4.7: Non-significant Hot Spots/Corridors (Primary Roads)

National Primary Routes
N14, N12, N19, N29, N33, N23, N26, N27, N28, N31

It is plausible that there may be more than one significant cluster on any particular road, thus results from Nagarwalla's scan must be expanded to examine all possible lambda values (as opposed to looking solely at the maximum lambda).

Table 4.8 shows the results obtained by examining all significant lambda values when lambda values are not ranked by maximum values and spanning distances of each cluster are not restricted to a particular distance e.g. a cluster of 10km in length or a cluster of 700m in length may be identified). Table 4.8 arranges significant clusters according to their location on the road - starting at the beginning and finishing at the end of the road.

Table 4.8: All significant clusters: according to location on the road (unrestricted spanning distance)

Route	Cluster Length	Cluster Size	Cluster Location
M1	3.2km	15	M1 Jnct 2 - M1/M50 interchange
N1	3km	56	Swords Rd- Rutland Rd, Dublin City
N2	116m	5	N2/Regional Rd Jnct near Mullynure, Co. Monaghan
	72.6km	182	SE. of Edmondstown, Co. Meath -N2/N1 Jnct, Dublin City
N3	134m	7	N3/N55 Jnct - N3 (Dublin Rd)
	81.6km	266	Virginia, Co. Cavan - N3/N2 Jnct, Dublin City
N4	134km	277	SE. of Drumod, Co.Leitrim - N4/N1 Jnct, Dublin City
N5	16km	43	Bridge St. - N5/R310 Jnct, Westport, Co. Mayo
N6	6.8km	18	N6/N59 Jnct - N6/R446 Jnct, Galway, Co. Galway
	45.4km	41	Aughrim, Co. Galway - E. of Athlone, Co.Westmeath
N7	1.6km	13	N7 (Dublin Rd) near Daly's Cross Co. Limerick
	38.1km	101	M7 Jnct 12 (Curragh) - N7/M50 interchange
N8	24.7km	55	N8/N22 Jnct Cork, Co. Cork - M6 Jnct 16
	29km	63	N8 (Cullahill) - N8/M7 Jnct, Co. Laois
N9	81.8km	97	SW. of Castledermot, Co. Kildare - N9/N25 Jnct, Co. Carlow
N10	1.1km	9	S. of Floodhall, Co. Kilkenny
	227m	5	Ring Rd. Kilkenny, Co. Kilkenny
N11	86.4km	296	N. of Courteencurragh, Co. Wexford - N11/ N4 Jct, Dublin City
N13	2.1km	14	Mill Rd, Moyle, Co. Donegal
N15	512m	8	N15 (Bundoran Rd) Co. Sligo
	102m	6	N15 (Dongeal Rd) - N15/R232 Jnct Co. Donegal
N16	35.1km	30	N16 (Ash Ln) Co. Sligo - Cullentragh, Co. Leitrim
N17	2.9km	17	Laghtgeorge - S. of Carraghy, Co. Galway
N18	829m	10	N18 (Ennis Rd) Co. Clare

Continued on next page

Table 4.8 –All significant clusters: according to location on the road (contd.)

Route	Cluster Length	Cluster Size	Cluster Location
N20	4.8km	31	N22/N20 Jnct - New Mallow Rd, Cork, Co. Cork
	1.6km	14	Main St. - Limerick Rd. Charleville, Co. Cork
	16m	5	O'Rourkes Cross, Co. Cork
	4.1km	26	N20/N18 Jnct - Rutland St. Limerick, Co. Limerick
N21	728m	11	Convent St. - Bridge St. Abbeyfeale, Co. Limerick
N22	3.8km	23	N22 (Carrigrohane Rd) - N22/N20 Jnct, Cork, Co. Cork
	19.3km	66	N22/N72 Jnct - N22/N23 Jnct, Farranfore, Co. Kerry
N24	1.2km	12	N24/Haywood Rd Jnct -N24/R689 Jnct Clonmel, Co. Tipperary
N25	47.8km	116	N25/N71 Jnct - Lagile, Co. Cork
	4.8km	25	N25 (Waterford Rd), New Ross - Pigotts, Co. Wexford
	677m	9	N25 near Larkins Cross, Co. Wexford
N30	323m	7	Mill Park Rd - N30/R702 Jnct, Enniscorthy, Co. Wexford
N32	322m	5	Malahide Rd, Dublin
M50	41.2km	166	M50 Jnct 17 - M50 Jnct 1 (Coolock Rd)

Table 4.8 indicates that there are many clusters with large spanning distances apparent on the vast majority of national primary routes. Identification of clusters with large spanning distances are of dubious practical value, thus the question of how to address the issue of secondary cluster extraction was pursued. Initially significant clusters with spanning distances less than or equal to 5km (collision corridors) and 500m (collision hot spots) were extracted. This approach was problematic as the process by which the clusters were extracted was subject to issues of overlapping clusters and roll-over clusters,

Figure 4.3: Overlapping clusters

Figure 4.4: Roll-over clusters

Figure 4.3 gives an illustration of overlapping clusters - cluster 1 (pink) finishes within cluster 2 (black) and Figure 4.4 illustrates the issue of roll-over clusters, which occur when cluster 1 (pink) finishes in the same location as cluster 2 (black) begins. The other issue associated with this approach (of extracting clusters based on their location from the start of the road) is that the original most likely cluster (based on maximum lambda value) is subsumed into a larger spanning cluster e.g. if a significant cluster based on its location from the start of the road has a spanning distance of 40km and the spanning distance of the most likely cluster (based on max lambda approach) only spans a distance of 2km.

A possible solution to the issue of overlap/roll-over clusters and large spanning distances is to return to the original approach (Figure4.5) of extracting the most likely cluster (based on maximum lambda value) and then use a systematic approach to extend this (original) approach and enable the researcher to identify multiple clusters along a linear network. The systematic approach (Figure4.6) extracts the most likely cluster (based on max lambda value), and extends this original approach by examining remaining significant clusters and extracting the next most significant cluster that does not overlap the initial cluster and select this cluster (based on its maximum lambda value). This process is repeated until there are no further clusters.

Figure 4.5: Most likely cluster (Max lambda)

Figure 4.6: Significant Clusters (Systematic approach)

The N2 national primary road will be used to illustrate the issues associated with multiple cluster extraction and results from the suggested extraction solution as are also outlined below.

4.5.1 N2 National Primary Road

The N2 connects Dublin City to the Northern Ireland Border at Moybridge, near Aughnacoly, Co. Tyrone to connect Dublin with Derry via the A5. Three hundred and twenty nine road traffic collisions were recorded on the N2 road from 2005-2009. The scan statistic was run on 272 road traffic collisions as collisions with geographical coordinates located more than 100m from the N2 road were excluded from the analysis*.

Extracting the most likely cluster based on the maximum lambda value identifies a road collision corridor of length 6.7km containing 75 road traffic collisions. (Table 4.9 gives details of this cluster (labelled Cluster 1)). If the approach of extracting clusters based on all possible lambda values (as opposed to looking solely at the maximum lambda) i.e. clusters are arranged according to their location on the road - starting at the beginning and finishing at the end of the road, then two clusters are identified on the N2. The first cluster is 116m and contains 5 collisions and the second cluster is 72.6km in length and contains 182 collisions. The original most likely cluster (by maximum lambda value) which spans 6.7km is now subsumed into a larger cluster spanning 72.6km

*Before the use of georeferencing devices (e.g. Garmin/ Tom Tom), co-ordinates were manually taken with paper maps which sometimes lead to inaccuracies in grid reference locations

in length. Extracting significant clusters by restricting spanning distances to 500m identifies 6 clusters on the N2 road (with 3 occurring in Dublin City). Figure 4.7 shows the geographical location of the clusters in Dublin City. The cluster identified in Finglas Rd. contains two roll-over clusters (500m in length each) and contains a total of 21 collisions. The cluster identified on Phibsborough Rd. (500m in length) contains 13 collisions and the cluster identified on Berkley Rd. (500m in length) contains 11 collisions.

Comparison of the clusters identified via restricting cluster spanning distance to 500m with the speed prone zones identified by An Garda Síochána indicates that speed collision prone zones were identified for Finglas Rd. (approx. 2.7km in length) and Phibsborough Rd. (approx. 1.1km in length) however the Gardaí do not have a collision prone zone for Berkley Rd.

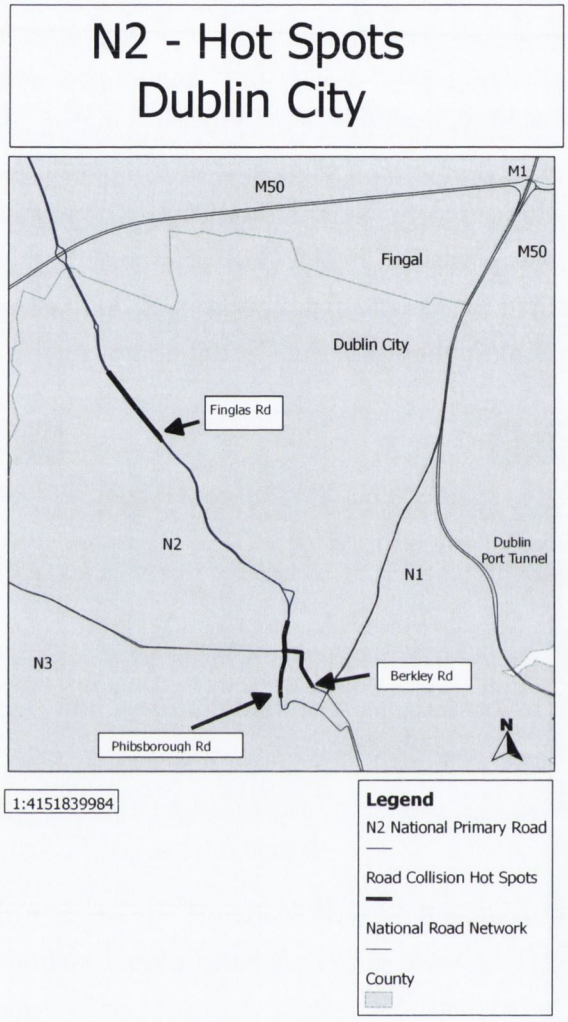

Figure 4.7: N2 Collision Hot Spots/Corridors: Dublin City

Applying the suggested systematic approach of extracting the most likely cluster (based on maximum lambda value) and then examining the remaining clusters and extracting the next most significant cluster that does not overlap initial cluster (and select this cluster on maximum lambda value) has identified four clusters for the N2 road

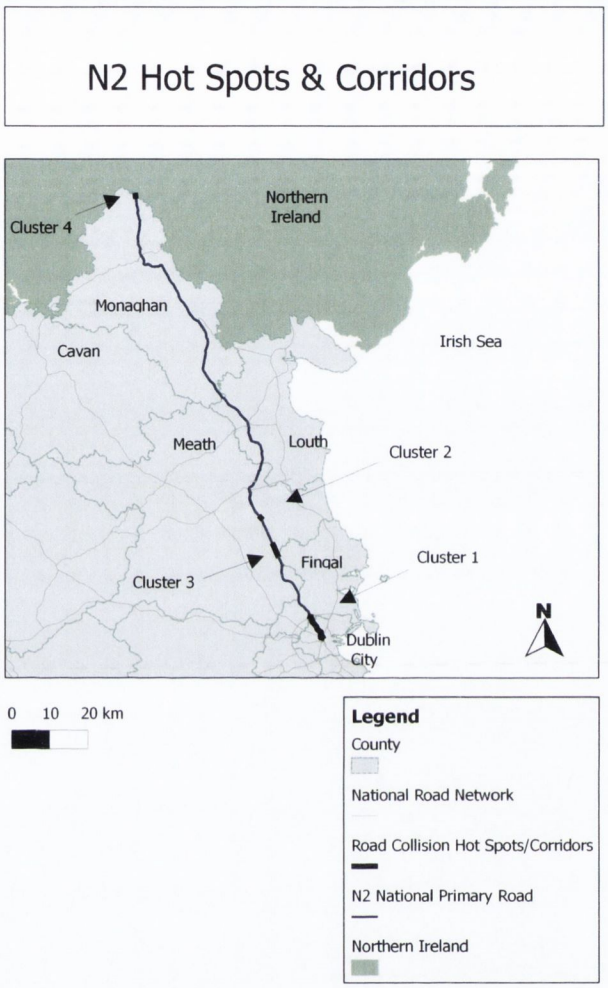

Figure 4.8: N2 Collision Hot Spots/Corridors

Table 4.9 gives detailed description of each cluster identified using the systematic approach. Cluster 1 denotes the original most likely cluster (based on maximum lambda value). A geographical representation of the clusters can be seen in the map: N2 hot spots and corridors (Figure 4.8).

- **Cluster 1**
  - Location: N2 (North Road), Dublin 11 - N2/Upper Dorset Street intersection, Dublin City
  - Number of collisions: 75
  - Length: 6.7km

Approximately 57.3% (43/75) of the collisions recorded in cluster 1 were multi-vehicle collisions and 20% (15/75) were pedestrian involved collisions. Ninety six percent (72/75) collisions recorded occurred during the hours of darkness and 69.3% (52/75) occurred on a weekday. Approximately 64% (48/75) occurred on a dry road surface and 81.3% (61/75) occurred on sections of road with speed limits 60km/h and below. The majority of injuries sustained were minor injuries, three serious injuries and two fatalities were recorded in this cluster.

- **Cluster 2**
  - Location: N2/R150 intersection, Flemington, Co. Meath
  - Number of collisions: 5
  - Length: 25m

Approximately 60% (3/5) of the collisions recorded in cluster 2 were multi-vehicle collisions. Eighty percent (4/5) of collisions recorded occurred during the hours of darkness and 60% (3/5) occurred on a weekday. Approximately 80% (4/5) occurred on a dry road surface, all occurred at a junction and 80% (4/5) occurred on sections of road with speed limit 100km/h. Six of the injuries sustained were minor injuries, two serious injuries and zero fatalities were recorded in this cluster.

- **Cluster 3**
  - Location: Cushinstown, (Ed Kilbrew), Co. Meath - North Road, (North east of Coolfore) Co. Meath
  - Number of collisions: 21
  - Length: 2.6km

Approximately 71.4% (15/21) of the collisions recorded in cluster 3 were multi-vehicle collisions. Seventy six percent (16/21) of collisions recorded occurred during the hours of darkness and 66.6% (14/21) occurred on a weekday. Approximately 52.3% (11/21) occurred on a dry road surface, 42.8% (9/21) occurred at a junction and 95.2% (20/21)

occurred on sections of road with speed limit 100km/h. Twenty six of the injuries sustained were minor injuries, five serious injuries and two fatalities were recorded in this cluster.

- **Cluster 4**
  - Location: N2/Regional roads near Mullynure, Co. Monaghan
  - Number of collisions: 5
  - Length: 116m

All of the collisions recorded in cluster 4 were multi-vehicle collisions. Sixty percent (3/5) of collisions recorded occurred during the hours of darkness and 60% (3/5) occurred on a weekday. Approximately 40% (2/5) occurred on a dry road surface, 20% (1/5) occurred at a junction and 60% (3/5) occurred on sections of road with speed limit 100km/h. Four of the injuries sustained were minor injuries, two serious injuries and zero fatalities were recorded in this cluster.

Comparison to the four clusters identified with the speed prone zones identified by An Garda Síochána indicates that speed collision prone zones identified by the Gardaí span larger distances than the collision hot spots/corridors identified via scan statistics, e.g. the speed collision prone zone identified at the North Road spans approx 3.15km where as the collision corridor identified via scan statistics spans 2.6km (see cluster 3 above). Similarly the speed collision prone zone identified near Mullynure, Co. Monaghan spans approximately 2km in length and the collision hot spot identified via scan statistics spans 25m (see cluster 4 above). There were five remaining speed collision prone zones identified by the Gardaí that were not detected via scan statistics, however there was one collision hot spot that was identified via scan statistics that was not identified by the Gardaí (see cluster 2 above).

Table 4.9: N2 Road Collision Hot Spots/Corridors

Description	Cluster 1	Cluster 2	Cluster 3	Cluster 4
Total Number of Collisions	**75**	**5**	**21**	**5**
Collision Type				
Pedestrian	15	0	0	0
Single Vehicle	8	1	1	0
Head-on	3	1	0	2
Angle	11	2	5	1
Rear-end	29	0	8	2
Unknown	6	1	7	0
Light				
Hours of daylight	2	1	4	2
Hours of darkness	72	4	16	3
Unknown	1	0	1	0
Day				
Weekday	52	3	14	3
Weekend	22	2	7	1
Bank holiday weekend	1	0	0	1
Road Surface				
Dry	48	4	11	2
Wet	23	1	9	2
Other/Unknown	4	0	1	1
Junction				
Yes	33	5	9	1
No	42	0	12	4
Speed Limit				
$\leq$ 60 km/h	61	1	1	2
80km/h	3	0	0	0
100km/h	11	4	20	3
120km/h	0	0	0	0
Injuries				
Fatal	2	0	2	0
Serious	3	2	5	2
Minor	98	6	26	4
Not Injured/Unknown	1	0	0	0

The most likely cluster (identified by max. lambda value) runs from the North Rd. (incorporating Finglas Rd) as far as the N1/N2 junction (thus incorporating Phibsborough Rd. and Berkley Rd.) This cluster is 6.7km in length and contains 75 collisions. In comparison to the Garda designated speed collision zones and the approach of restricting cluster spanning distance to (500m/5km) which identified three clusters in Dublin City, each containing 21, 13 and 11 collisions respectively, the maximum lambda approach

identifies one significant collision corridor in Dublin City of 6.7km in length (i.e. instead of having three individual clusters or three speed collision prone zones there is one significant collision corridor).

Table 4.10 shows road collision corridors and hot spots identified through the application of Nagarwalla's scan statistic on all national primary roads in the Republic of Ireland. Extraction of the most likely collision hot spots/corridors and secondary collision hot spots/corridors were identified by maximum lambda values (as outlined above).

Table 4.10: All significant clusters: systematic approach to extract max lambdas

Route	Cluster Length	Cluster Size	Cluster Location
M1	1.4km	11	M1/M50 interchange, Dublin
N1	3.1km	56	Swords Rd-Parnell St, Dublin City
N2	6.7km	74	North Rd-N2/Upper Dorset Street Jct, Dublin
	25m	5	N2/R150 Jnct, Flemington, Co. Meath
	2.6km	21	Cushinstown, (Ed Kilbrew)-North Rd, Co. Meath
	116m	5	N2/Regional Rd Jnct near Mullynure, Co. Monaghan
N3	183m	15	NW of Blackbull, Co. Meath
	1.6km	24	NW of Cooksland-Main St. Dunsaughlin, Co. Meath
	134m	7	SE of Annagelliff-Dublin Rd, Co. Cavan
	137m	6	South of Ross (Ed Tara), Co. Meath
	2.7km	30	Navan Rd-North Circular Rd/Phibsborogh Rd Jnct, Dublin
N4	14.7km	112	Leixlip Rd-Aston Quay/Westmoreland St. Jnct, Dublin
	1.1km	14	NW of Ballymahon Rd-Edgeworthstown, Co. Longford
N5	9.9km	33	W of Cloggernagh East-Bridge St. Westport,Co. Mayo
N6	465m	25	Dun Na Coiribe-Headford Rd, Galway, Co. Galway
	7.5km	19	Athlone bypass-Dublin Rd, Co. Westmeath
	1.1km	9	SW of BallyDangan-SW of Toberiheen, Co. Roscommon
N7	43m	7	Newlands Cross, Lucan, South Dublin
	574m	11	SW of Daly's Cross, Castleconnell-Dublin Rd, Co. Limerick
	22.1km	65	M7 (Nass Road)-W of Newlands Cross, South Dublin
N8	6.5km	38	N8/N22 Jnct- NE of Richmond, Co. Cork
	2.9km	25	Main St., Abbeyleix-S of Corbally, Co. Laois
N9	35km	95	Mill St, Co. Kilkenny-R705/N9 Jnct Co. Carlow
N10	81m	6	S of Flood Hall-Floodhall, Co. Kilkenny
	227m	5	Ring Road Kilkenny, Co. Kilkenny
N11	15.1km	147	Dublin Rd-Leinster St/Kildare St Jnct, Dublin
	22m	5	Jack White Cross Roads, Co. Wicklow
	3.1km	30	Barndarrig-S of Ballinameesda Upper, Co. Wicklow
N13	732m	9	SW of Moyle-NE of Moyle, Co. Donegal
N15	75m	5	Bundoran Rd, Sligo, Co. Sligo
	27m	5	Donegal Rd/R332 Jnct, Co. Donegal

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Table 4.10 – All significant clusters: systematic approach to extract max lambdas (contd.)

Route	Cluster Length	Cluster Size	Cluster Location
N16	45.5km	37	Newline-E of Tomrud, Co. Leitrim
N17	190m	8	N17/R331 (Ballydine Rd) Jnct, Co. Mayo
	958m	12	N17/N63 Jnct - SW of Laghtgeorge, Co. Galway
N18	92m	6	Coonagh Roundabout, Limerick, Co. Limerick
N20	16m	5	N20/R518 Jnct, Limerick, Co. Limerick
	1.5km	19	North Ring Rd- Commons Rd, Cork, Co. Cork
	208m	7	Main St Charleville-Limerick Rd Charleville, Co. Cork
N21	728m	11	Convent Rd-Bridge St Abbeyfeale, Co. Limerick
N22	689m	14	N72/N22 Jnct-Lissivigeen Rd, Co. Kerry
	729m	13	St. Patricks St.-N22/Washington St Jnct, Cork, Co. Cork
	123m	6	N22/R561 Jnct-N of N22/R561 Jnct, Farranfore, Co. Kerry
N24	1.2km	12	Haywood Rd-N24/R689 Jnct, Clonmel, Co. Tipperary
N25	31.7km	99	Bandon Rd Roundabout-E of Ballyedekin, Co. Cork
	51m	6	SW of N30/N25 Jnct, Co. Wexford
	63m	6	W of Larkins Cross-Larkins Cross Co. Wexford
N30	323m	7	Mill Park Rd-Abbey Sq, Enniscorthy, Co. Wexford
N32	322m	5	Malahide Rd, Dublin
M50	36.5km	160	SE of Jnct 15 M50-Jnct 1 M50, Dublin

Examination of Table 4.10 indicates that clusters identified on some roads have very large spanning distances e.g. M50 motorway collision corridor is 36.5km, possible explanations for this are outlined below.

4.5.2 M50 Motorway

The M50 motorway is a national primary road which runs from Junction 1 at Dublin Port tunnel to Junction 17 which merges with the M11 (Dublin - Wexford national primary route). One hundred and eighty road traffic collisions were recorded on the M50 road from 2005-2009. The scan statistic was run on 168 road traffic collisions as collisions with geographical coordinates located more than 100m from the M50 road were excluded from the analysis. One cluster (denoted cluster 1) was identified, and Table 4.11 gives detailed description of this cluster. A geographical representation of this cluster identified on the M50 motorway can be seen in Figure 4.9.

- **Cluster 1**
  - Location: South East of Junction 15 M50 - M50, Junction 1
  - Number of collisions: 160
  - Length: 36.5km

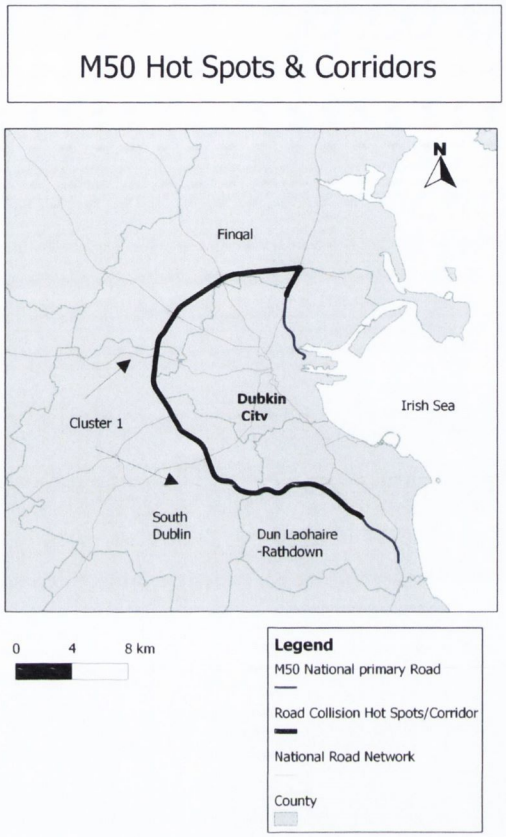

Figure 4.9: M50 Collision Hot Spots/Corridors

Approximately 61.3% (98/160) of the collisions recorded in cluster 1 were multi-vehicle collisions and 20.6% (33/160) were single vehicle collisions. Ninety four percent of collisions recorded occurred during the hours of darkness and 72.5% (116/160) occurred on a weekday. Approximately 66.9% (107/160) occurred on a dry road surface, 11.9% (19/160) occurred at a junction and 50.6% (81/160) occurred on sections of road with speed limits 120km/h and 38.8% (62/160) occurred sections with speed limits of 60km/h or less. Two hundred and twenty two injuries sustained were minor injuries, ten serious injuries and four fatalities were recorded in this cluster.

Table 4.11: M50 Road Collision Hot Spots/Corridors

Description	Cluster 1
Total Number of Collisions	**160**
Collision Type	
Pedestrian	2
Single Vehicle	33
Head-on	4
Angle	12
Rear-end	82
Unknown	27
Light	
Hours of daylight	6
Hours of darkness	150
Unknown	4
Day	
Weekday	116
Weekend	41
Bank holiday weekend	3
Road Surface	
Dry	107
Wet	45
Other/Unknown	8
Junction	
Yes	19
No	141
Speed Limit	
$\leq$ 60 km/h	62
80km/h	8
100km/h	9
120km/h	81
Injuries	
Fatal	4
Serious	10
Minor	222
Not Injured/Unknown	44

The primary reason that the M50 collision corridor has a very large spanning distance of 36.6km is due to the fact that road traffic collision data does not contain information on the direction of travel, thus as a result collisions that occur in the Northbound lane of the M50 are amalgamated with collisions occurring on the Southbound lane. This amalgamation of collisions results in highly inflated numbers of collisions which should in reality be treated independently.

4.6 Overview: National Primary Road Hot Spots & Corridors

A total of 1318 road traffic collisions were recorded for all the identified collision hot spots/corridors. Approximately 54.2% (714/1318) of these collisions were multi-vehicle collisions, 85.7% (1129/1318) occurred during the hours of darkness and 70.8% (933/1318) occurred on a weekday. Seventeen percent (219/1318) of these collisions resulted in at least one fatal/serious injury, 46.7% (616/1318) occurred in sections of road with a speed limit of 60km/h or less and 32.9% of collisions recorded occurred at a junction. Graphical images of road collision hot spots and corridors are given for each individual national primary road. Appendix .7, p.191 provides maps and tables (11 - 32) giving details relating to road traffic collisions in collision hot spots/corridors for each national primary road.

4.7 National Secondary Roads

The systematic approach* was used to identify multiple clusters on national secondary roads, however, in addition to the use of scan statistics, semantic segmentation (as outlined in Chapter 3, p.44) was also required. National primary roads are continuous roads (that are major long distance through roads linking the principal ports or airports, cities and large towns), however national secondary roads (are medium distance through roads connecting important towns and linking up to the national primary roads) and regional roads (provide the main links between national roads), thus continuity of secondary/regional roads are broken by national primary roads.

There are 34 national secondary routes in the Republic of Ireland. Table 4.12 shows the results of the scan statistic analysis to identify significant hot spots/corridors. There were insufficient evidence to find statistically significant hot spots/corridors on a number of national secondary roads (Table 4.13 provides a list of these roads). The N52 will be used to illustrate semantic segmentation and the application of scan statistics to identify collision hot spots/corridors on national secondary roads in Ireland. The N81 national secondary road is an example of continuous road (i.e. continuity not broken via national primary roads). Initially scan statistics will be applied to this road (in the same manner as for national primary roads i.e. no semantic segmentation). Following this approach, the N81 is broken into semantic segments based on speed limits and scan statistics are applied to each speed zone segment to identify collision hot spots/corridors. Table 4.12 provides a list of road traffic collision hot spots/corridors identified on national secondary

*tested at the 5% level of statistical significance

roads via scan statistics (with semantic segmentation) using the systematic approach to detect multiple clusters.

Table 4.12: National Secondary Road Hot Spots/Corridors

Route	Length	Cluster	Location
N51: Section 1	309m	5	O'Growney St. - Main St, Athboy, Co. Meath
N52: Section 1	1.4km	9	S. - N. of Durrow Demense, Co. Offaly
N52: Section 4	14m	5	Dundalk bypass/Barrack St. Jnct
			Dundalk, Co.Louth
	373m	7	Eastern Bypass Rd, Co. Louth
N54: Section 1	2.4km	9	Cavan Rd - Gannons Cross, Co. Cavan
N55: Section 2	179m	6	NE. of Cranalagh More, Co. Longford
N56	11.0km	36	NW. of Knocknabollan - Letterkenny,Co. Donegal
	752m	8	W. of Mountcharles-NW. of Turrishill,Co. Donegal
N59: Section 1	810m	6	Quay St. - Newport St. Westport, Co. Mayo
N59: Section 2	1.5km	17	Sligo Rd - Dillon Terrace, Ballina, Co. Mayo
	241m	5	Newport Rd/Paddock Jnct - North Mall/
			Newport St. Jnct, Westport, Co. Mayo
N61	11.6km	27	Near Casheltauna - Athlone Rd, Co. Roscommon
N67: Section 2	12.3km	23	N67/Glenveil Rd Jnct - Ballycarraeile, Co. Clare
N69	39m	5	R521 (Askeaton Rd)/N69 Jnct, Co. Limerick
	1.8km	13	Glenameade Rd - West of Coolbeg, Co. Limerick
	290m	6	Clarina-N69/Ballybrown Jnct, Co. Limerick
N70	22.3km	36	Tralee, Co.Kerry - Tinnahally, Co. Kerry
N71: Section 1	51.0km	90	Churraigh - Hawkes Rd, Cork, Co. Cork
N72: Section 2	17m	5	R579/N72 Jnct, Ballyquirk, Co. Cork
	221m	5	W. of The Fair Field - The Fair Field, Co. Cork
N76	1.2km	12	Rathaleek - Callan Rd, Co. Kilkenny
N77	4.2km	11	Suttonsrath - Castlecomer Rd Co. Kilkenny
N78	6.9km	21	Duke St. Athy - SW of Kilmeade, Co. Kildare
N80	15m	6	R745/N80 intersection, Co. Wexford
	1.3km	13	Tullow Rd - Wexford Rd Carlow, Co. Carlow
	769m	8	Derrybeg - S. of Derrybeg,(Geashill By),Co. Offaly
N81	14.8km	147	R136/N81 Jnct - College Green, Dublin City
	288m	11	N81/R410 Jnct - Main St. Blessington,
			Co. Wicklow
N83: Section 1	799m	5	Cloonfad - Riverbank/N83 Jnct, Co. Roscommom
N84: Section 1	4.4km	18	S. of Carrowbrowne - Ballinfoyle, Co. Galway

Table 4.13: Non-significant Hot Spots/Corridors (Secondary Roads)

National Secondary Roads	
Whole road	N57, N58, N60, N64, N65, N66, N68
	N73, N74, N75, N79, N82, N85, N86, N87
Road - Section 1	N53,N55,N62,N63,N67,N72
Road - Section 2	N51, N52, N53, N54, N62, N63, N71, N83
Road - Section 3	N52, N54, N62

4.7.1 Overview: National Secondary Road Hot Spots & Corridors

A total of 625 road traffic collisions were recorded for all the identified collision hot spots/corridors. Approximately 46.7% (292/625) of these collisions were multi-vehicle collisions, 79.2% (495/625) occurred during the hours of darkness and 65% (406/625) occurred on a weekday. Eighteen percent (110/625) of these collisions resulted in at least one fatal/serious injury, 45.3% (283/625) occurred in sections of road with a speed limit of 100km/h or less and 31.5% (197/625) of collisions recorded occurred at a junction. Graphical images of road collision hot spots and corridors are given for each individual national secondary road and Tables 33 - 48 in Appendix provide corresponding details and maps of road traffic collisions occurring in these collision corridors and hotspots.

4.7.2 N52 National Secondary Road

The N52 national secondary road which runs from Nenagh, Co. Tipperary to Dundalk, Co. Louth. For the purposes of this analysis, the N52 was split into sections. Section 1 runs from Nenagh Co. Tipperary to M6 junction 6, section 2 runs from M6 junction 4 to N52/N4 intersection, section 3 runs from N52/N4/R400 intersection to N52/N3 intersection and section 4 runs from N52/N3 intersection to Dundalk, Co. Louth. Two hundred and sixty road traffic collisions were recorded on the N52 road from 2005-2009. The scan statistic was run on 211 road traffic collisions (58 in section 1, 20 in section 2, 82 in section 3 and 51 in section 4). Collisions with geographical coordinates located more than 100m from the N52 road were excluded from the analysis. One cluster was identified in section 1 and two clusters identified in section 4. Tables 4.14-4.15 give detailed description of each cluster. No significant clusters were identified in sections 2 and 3. A geographical representation of the clusters can be seen in the maps: N52 hot spots and corridors (Figures 4.10-4.11) .

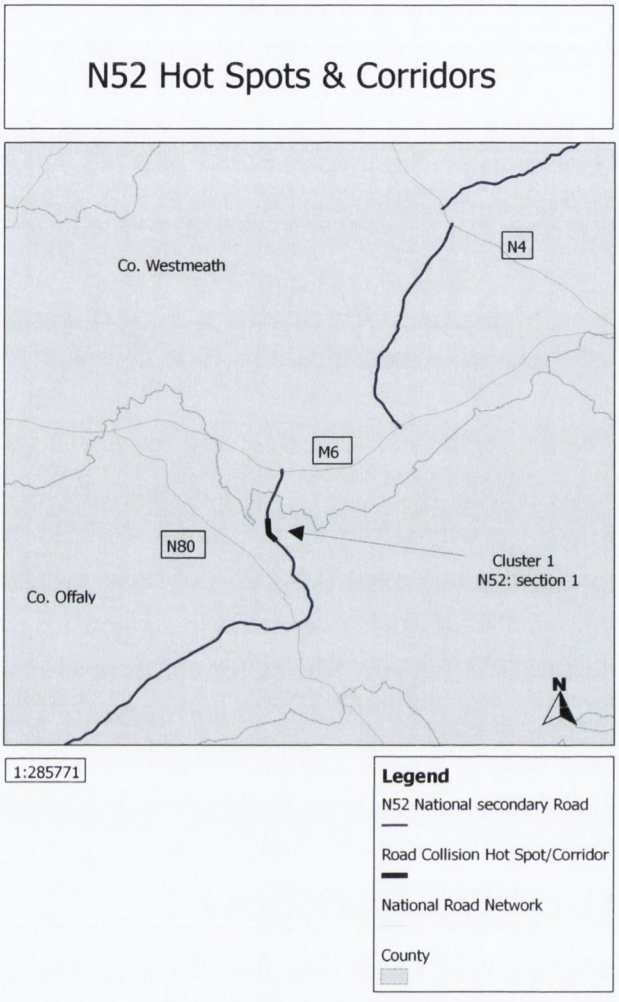

Figure 4.10: N52 Collision Hot Spots/Corridors

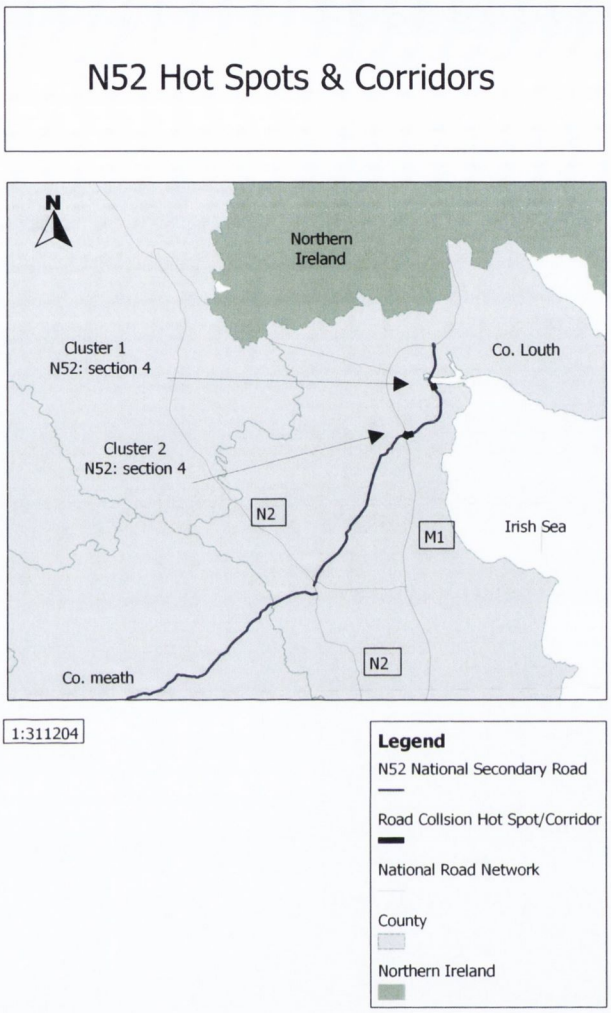

Figure 4.11: N52 Collision Hot Spots/Corridors

- **Section 1: Cluster 1**
  - Location: South of Durrow Demense, Co. Offaly - North of Durrow Demense, Co. Offaly
  - Number of collisions: 9
  - Length: 1.4km

Approximately 77.8% (7/9) of the collisions recorded in cluster 1 were multi-vehicle collisions and 55.6% (5/9) occurred during the hours of darkness and 66.7% (6/9) occurred on a weekday. Approximately 44.4% (4/9) occurred on a dry road surface, 22.2% (2/9) occurred at a junction and all occurred on sections of road with speed limits 100km/h. Fifteen injuries sustained were minor injuries, one serious injury and one fatality were recorded in this cluster.

- **Section 4: Cluster 1**
  - Location: Dundalk bypass/Barrack Street intersection, Dundalk Co. Louth
  - Number of collisions: 5
  - Length: 14m

Approximately 60% (3/5) of the collisions recorded in cluster 1 were multi-vehicle collisions and all occurred during the hours of darkness and 80% (4/5) occurred on a weekday. Approximately 80% (4/5) occurred on a dry road surface, All recorded collisions occurred at a junction and all occurred on sections of road with speed limits 60km/h or less. Seven injuries sustained were minor injuries, one serious injury and one fatality were recorded in this cluster.

- **Section 4: Cluster 2**
  - Location: Location: Eastern Bypass Road roundabout, Co. Louth - Eastern bypass Road, Co. Louth
  - Number of collisions: 7
  - Length: 373m

Approximately 71.4% (5/7) of the collisions recorded in cluster 2 were multi-vehicle collisions and all occurred during the hours of darkness and 85.7% (6/7) occurred on a weekday. Approximately 57.1% (4/7) occurred on a dry road surface, Approximately 85.7% (6/7) recorded collisions occurred at a junction and 42.9% (3/7) occurred on sections of road with speed limits 60km/h or less. Eight injuries sustained were minor injuries, one serious injury and zero fatalities were recorded in this cluster.

Table 4.14: N52 Section 1 Road Collision Hot Spots/Corridors

Description	Cluster 1
Total Number of Collisions	9
Collision Type	
Pedestrian	0
Single Vehicle	1
Head-on	4
Angle	2
Rear-end	1
Unknown	1
Light	
Hours of daylight	4
Hours of darkness	5
Unknown	0
Day	
Weekday	6
Weekend	3
Bank holiday weekend	0
Road Surface	
Dry	4
Wet	4
Other/Unknown	1
Junction	
Yes	2
No	7
Speed Limit	
$\leq$ 60 km/h	0
80km/h	0
100km/h	9
120km/h	0
Injuries	
Fatal	1
Serious	1
Minor	15
Not Injured/Unknown	0

Table 4.15: N52 Section 4 Road Collision Hot Spots/Corridors

Description	Cluster 1	Cluster 2
Total Number of Collisions	5	7
Collision Type		
Pedestrian	0	0
Single Vehicle	0	0
Head-on	1	0
Angle	2	2
Rear-end	0	3
Unknown	2	2
Light		
Hours of daylight	0	0
Hours of darkness	4	7
Unknown	1	0
Day		
Weekday	4	6
Weekend	1	1
Bank holiday weekend	0	0
Road Surface		
Dry	4	4
Wet	1	3
Other/Unknown	0	0
Junction		
Yes	5	6
No	0	1
Speed Limit		
$\leq$ 60 km/h	5	3
80km/h	0	1
100km/h	0	3
120km/h	0	0
Injuries		
Fatal	0	0
Serious	0	1
Minor	7	8
Not Injured/Unknown	0	0

Comparison of the clusters identified via semantic segmentation and scan statistics with the speed prone zones identified by An Garda Síochána indicates that none of the speed collision prone zones (7 in total) identified by the Gardaí corresponded to the collision hot spots/corridors identified via scan statistics. Two of these zones were designated in close proximity to road collision hot spots (section 4: clusters 1 & 2) e.g. travelling in an eastward direction towards Dundalk a speed collision zone (approx. 1.7km

in length) designated by the Gardaí occurred 500m after the road collision hot spot (14m in length) which contained 5 collisions where one fatality and one serious injured were sustained (see section 4: cluster 2). There were no Garda designated speed collision zones located in close proximity to the road collision corridor (1.4km in length) containing 9 collisions with one fatality and one serious injury (see section 1: cluster 1).

4.7.3 N81 National Secondary Road

The N81 runs from Dublin City to N81/N80 intersection, south of Tullow, Co. Carlow. Two hundred and seventy two road traffic collisions were recorded on the N81 road from 2005-2009. The scan statistic was run on 270 road traffic collisions. Collisions with geographical coordinates located more than 100m from the N81 road were excluded from the analysis. Two clusters were identified and Table 4.16 gives detailed description of each cluster. A geographical representation of the cluster can be seen in the map: N81 hot spots and corridors (Figure 4.12).

- **Cluster 1**
  - Location: N81 (Blessington Rd) intersection with R136 (Cheeverstown Rd.), Co. Dublin - College Green, Dublin City Centre
  - Number of collisions: 147
  - Length: 14.8km

Approximately 45.6% (67/147) of the collisions recorded in cluster 1 were multi-vehicle involved collisions, 20.4% (30/147) were pedestrian involved collisions, 95.9% (141/147) occurred during the hours of darkness and 76.9% (113/147) occurred on a weekday. Approximately 66% (97/147) occurred on a dry road surface, 44.2% (65/147) occurred at a junction and 65.3% (96/147) occurred on sections of road with speed limits 60km/h or less. One hundred and fifty nine injuries sustained were minor injuries, fifteen serious injuries and six fatalities were recorded in this cluster.

- **Cluster 2**
  - Location: N81 (Baltinglass Rd.), intersection with R410 (Naas Rd.), Blessington, Co. Wicklow - Main Street Blessington, Co. Wicklow
  - Number of collisions: 11
  - Length: 288m

Approximately 54.5% (6/11) of the collisions recorded in cluster 2 were multi-vehicle involved collisions, 27.3% (3/11) were pedestrian involved collisions, all occurred during the hours of darkness and 90.9% (10/11) occurred on a weekday. Approximately 81.8% (9/11) occurred on a dry road surface, 27.3% (3/11) occurred at a junction and 90.9% (10/11) occurred on sections of road with speed limits 60km/h or less. Ten injuries sustained were minor injuries, one serious injury and zero fatalities were recorded in this cluster.

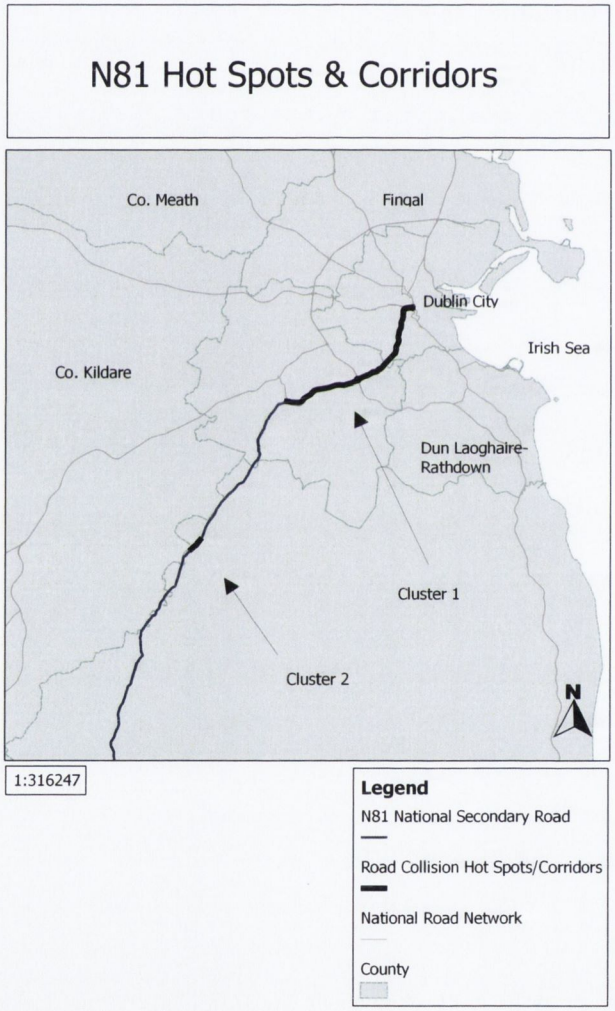

Figure 4.12: N81 Collision Hot Spots/Corridors

Table 4.16: N81 Road Collision Hot Spots/Corridors

Description	Cluster 1	Cluster 2
Total Number of Collisions	147	11
Collision Type		
Pedestrian	30	3
Single Vehicle	18	0
Head-on	12	0
Angle	20	1
Rear-end	35	5
Unknown	32	2
Light		
Hours of daylight	5	0
Hours of darkness	141	11
Unknown	1	0
Day		
Weekday	113	10
Weekend	32	1
Bank holiday weekend	2	0
Road Surface		
Dry	97	9
Wet	45	2
Other/Unknown	5	0
Junction		
Yes	65	3
No	82	8
Speed Limit		
$\leq$ 60 km/h	96	10
80km/h	24	1
100km/h	27	0
120km/h	0	0
Injuries		
Fatal	6	0
Serious	15	1
Minor	159	10
Not Injured/Unknown	15	1

The two clusters identified via scan statistics on the N81 both incorporate the speed collision zones identified by An Garda Síochána, however Cluster 1 (identified via scan statistics) has a large spanning distance. This cluster spans a distance of 14.1km and begins in College Green, Dublin City Centre and finishes at the N81/R136 (Cheeverstown Rd.) intersection. This collision corridor contains 147 collisions resulting in six fatal and fifteen serious injuries. The speed collision zones identified by the Gardaí for the same

section (i.e. from College Green to the N81/R136 intersection) account for two speed collision zones, one of which incorporates Harold's Cross (approx. 1.2km in length) and the other approx 1.5km in length incorporates the N81/R113 (Belgard Rd. intersection). The second cluster identified through the application of scan statistics occurs between the N81/R410 (Naas Rd.) intersection and Main Street in Blessington. This collision hot spot spanned a distance of 288m and contained 11 collisions. This hot spot occurs within an urban area where vehicles should be travelling (within speed limit) of 50/60 km/h thus collisions recorded within this hot spot resulted in zero fatalities and only one serious injury. The Garda designated speed zone in this area (Blessington, Co. Wicklow) incorporates the road collision hot spot (identified via scan statistics), however this speed collision zone has a larger spanning distance of approximately 4km (from N81/R410 to Hempstown Commons). There were five other speed collision zones (identified by the Gardaí) occurring on the N81 (primarily on sections of road with a speed limit of 100km/h) that were not detected via scan statistics, thus for the purposes of this analysis the N81 was sectioned into speed limit zones and scan statistics were run on each zone. Results from this analysis are outlined in section 4.7.4.

4.7.4 Speed Limit Zones

Sectioning the N81 into speed limit zones of 30km/h, 50km/h, 60km/h, 80km/h and 100km/h from the beginning of in College Green, Dublin City to N81/N80 intersection, south of Tullow, Co. Carlow resulted in 24 speed zones* Running the scan statistic on each zone identified clusters within three zones (see Figure 4.13). Zone 1 denotes a section of road in Dublin city with a speed limit of 50km/h. This zone spans a distance of approx. 12km. Zone 2 denotes a section of road on the Tallaght Bypass, South Dublin with a speed limit of 60km/h. This zone spans a distance of approx. 5km. Zone 3 denotes a section of road on the N81 (near Ballylion) in Co. Wicklow with a speed limit of 100km/h. This zone spans a distance of approx. 7.5km.

*A speed zone denotes a section of road with a specific speed limit e.g. 50km/h, 60km/h, etc.
A total of 24 zones were recorded:
Four zones had zero recorded collisions - the speed limits of these zones were: one 50km/h, one 80km/h section and two sections with a speed limit of 60km/h
Twelve zones had 1-8 collisions recorded - the speed limit of these zones were: zero 80km/h, two 50km/h, four 60km/h and four 100km/h sections.
Four zones had 11-13 recorded collisions - the speed limit of these zones were: zero 80km/h, one 30km/h, 50km/h, 60km/h and 100km/h sections.
Four zones had more than 20 collisions recorded. Three of these zones were in Dublin city/South Dublin with speed limits of 50km/h, 60km/h and 80km/h. The Fourth zone was located on the N81 on the west side of Poulaphoca, Co. Wicklow with a speed limit of 100km/h.

Table 4.17: Speed Zone Collision Hot Spots/Corridors

Route	Length	Cluster	Location
Zone 1: 50km/h	18m	5	New St. South/R110 Jnct, Dublin 8
Zone 2: 60km/h	6m	8	R136/N81 Jnct, South Co. Dublin
Zone 3: 100km/h	1.5km	15	S. of Ballylion Lower - Whitestown Upper, Co. Wicklow
	91m	5	N of R756 Jnct, Knockroe - R756/N81 Jnct, Co. Wicklow

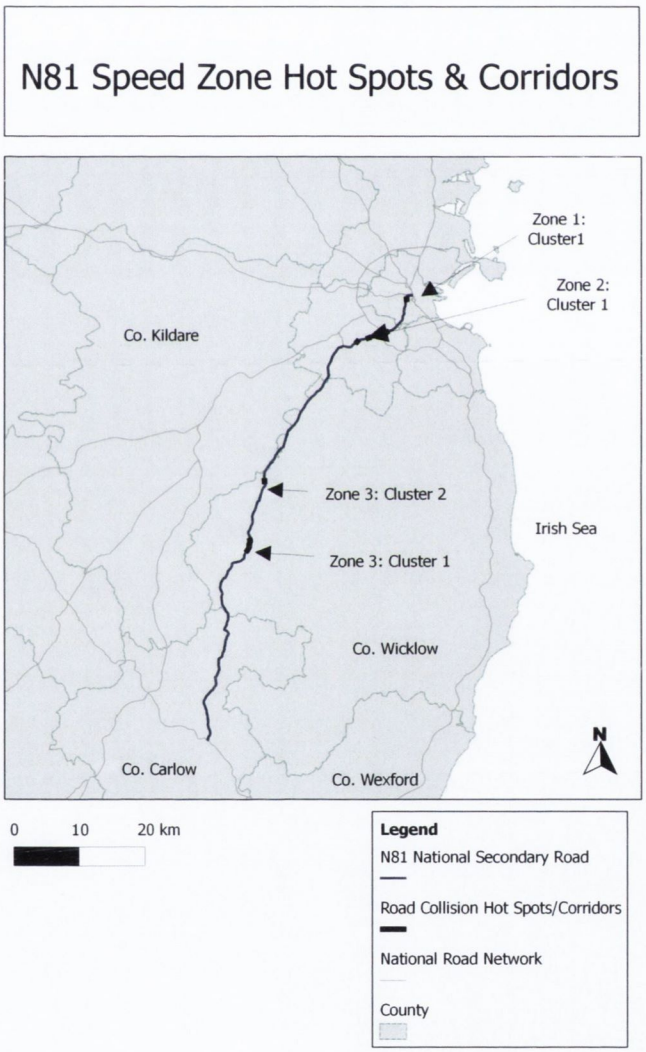

Figure 4.13: N81 Speed Zone Hot Spots/Corridors

One cluster was identified in Zone 1 (recorded collisions: ¿20), one cluster was identified in zone 2 (recorded collisions: ¿20) and two clusters identified in zone 3 (recorded collisions: ¿20).

- **Zone 1: Cluster 1**
  - Location: New Street South, Dublin 8 - New Street South/R110 intersection, Dublin 8
  - Speed limit: 50km/h
  - Number of collisions: 5
  - Length: 18m

Approximately 60% (3/5) of the collisions recorded in cluster 1 were multi-vehicle involved collisions, all occurred during the hours of darkness and 80% (4/5) occurred on a weekday. Approximately 80% (4/5) occurred on a dry road surface, 80% (4/5) occurred at a junction and all occurred on sections of road with speed limits 60km/h or less. Four injuries sustained were minor injuries, one serious injury and zero fatalities were recorded in this cluster.

- **Zone 2: Cluster 1**
  - Location: R136 (Cheeverstown Rd)/N81(Tallaght Pass) intersection, South Co. Dublin
  - Speed limit: 60km/h
  - Number of collisions: 8
  - Length: 6m

Approximately 62.5% (5/8) of the collisions recorded in cluster 1 were multi-vehicle involved collisions, all occurred during the hours of darkness and 62.5% (5/8) occurred on a weekday. Approximately 50% (4/8) occurred on a dry road surface, 87.5% (7/8) occurred at a junction and 37.5% (3/8) occurred on sections of road with speed limits 60km/h or less. Sixteen injuries sustained were minor injuries, one serious injury and zero fatalities were recorded in this cluster.

- **Zone 3: Cluster 1**
  - Location: South of Ballylion Lower, Co. Wicklow - Whitestown Upper, Co. Wicklow
  - Speed limit: 100km/h
  - Number of collisions: 15
  - Length: 1.5km

Approximately 66.7% (10/15) of the collisions recorded in cluster 1 were multi-vehicle involved collisions, 73.3% (11/15) occurred during the hours of darkness and 73.3% (11/15) occurred on a weekday. Approximately 20% (3/15) occurred on a dry road surface, 6.7% (1/15) occurred at a junction and 73.3% (11/15) occurred on sections of road with speed limits 100km/h. Twenty two injuries sustained were minor injuries, zero serious injuries and zero fatalities were recorded in this cluster.

- **Zone 3: Cluster 2**
  - Location: R756 Knockroe, Co. Wicklow - R756/N81 intersection, Co. Wicklow
  - Speed limit: 100km/h
  - Number of collisions: 5
  - Length: 91m

Approximately 60% (3/5) of the collisions recorded in cluster 2 were multi-vehicle involved collisions, all occurred during the hours of darkness and 60% (3/5) occurred on a weekday. Approximately 20% (1/5) occurred on a dry road surface, all occurred at a junction and 80% (4/5) occurred on sections of road with speed limits 100km/h. Seven injuries sustained were minor injuries, zero serious injuries and one fatality were recorded in this cluster.

Table 4.18: N81 Speed Zone Collision Hot Spots/Corridors

Description	Zone 1 Cluster 1	Zone 2 Cluster 1	Zone 3 Cluster1	Zone 3 Cluster 2
Total Number of Collisions	5	8	15	5
Collision Type				
Pedestrian	0	1	0	0
Single Vehicle	0	0	10	1
Head-on	0	0	3	2

Continued on next page

Table 4.18 – N81 Speed Zone Collision Hot Spots/Corridors

Description	Zone 1 Cluster 1	Zone 2 Cluster 1	Zone 3 Cluster1	Zone 3 Cluster 2
Angle	1	2	1	1
Rear-end	2	3	0	0
Unknown	2	2	1	1
Light				
Hours of daylight	0	0	4	0
Hours of darkness	5	8	11	5
Unknown	0	0	0	0
Day				
Weekday	4	5	11	3
Weekend	1	3	3	2
Bank holiday weekend	0	0	1	0
Road Surface				
Dry	4	4	3	1
Wet	1	3	11	4
Other/Unknown	0	1	1	0
Junction				
Yes	4	7	1	5
No	1	1	14	0
Speed Limit				
$\leq$ 60 km/h	5	3	1	1
80km/h	0	2	3	0
100km/h	0	3	11	4
Injuries				
Fatal	0	0	0	1
Serious	1	1	0	0
Minor	4	16	22	7
Not Injured/Unknown	0	4	0	0

Sectioning the N81 national secondary road into speed limit zones and running scan statistics to identify collision hot spots/corridors has indicated three hot spots and one collision corridor. All of the hot spots identified contained one fatal/serious injury. Comparing the location of these collision hot spots/corridors to the Garda speed collision zones indicates that only one hot spot is incorporated in the Garda designated speed collision zone list - this hot spot (zone 3, cluster 2) is located at the N81/R756 intersection, Knockroe, Co. Wicklow. The Garda speed collision zone is approximately 2km in length and incorporates this 91m hot spot which contained 5 collisions and resulted in one fatality. The road collision corridor (zone 3, cluster 1) occurs approximately 2km after a designated Garda speed collision zone (when travelling southwards on the N81). This collision corridor begins before the N81 intersection with the R412 regional road and fin-

ishes near the N81 intersection with two local roads at Whitestown Upper, Co. Wicklow. None of the injuries sustained from road traffic collisions in this collision corridor were fatal/serious injuries. The remaining two collision hot spots (zone 1, cluster 1 and zone 2, cluster 1, identified via scan statistics) were not part of the Garda designated speed collision zones, however were contained in the original road collision corridor identified (via scan statistics) in section 4.7.3, p.87.

4.8 Regional Roads

The Irish road network is predominately characterised by regional and local roads. These roads provide the main links between national roads and include all other urban and rural roads. For the purpose of this study, two regional roads were analysed. Table 4.19 shows the significant collision hot spots/corridors that were identified by scan statistics.

Table 4.19: Road Collision Hot Spots/Corridors

Route	Length	Cluster	Location
R423	1.3km	5	Clonygowan - SW of Esker, Co. Laois
R402	1.9m	23	Dublin Rd. - St. Mary's Rd, Edenderry, Co. Offaly

4.8.1 R423 Regional Road

The R423 regional road runs from Mountrath, Co. Laois to the intersection with regional road R445. Seven road traffic collisions were recorded on the R423 road from 2005-2009. The scan statistic was run on 7 road traffic collisions. No collisions had geographical coordinates located more than 100m from the R423 road. One cluster was identified and Table 4.20 gives detailed description of this cluster. A geographical representation of the cluster can be seen in the map: R423 hot spots and corridors (Figure 4.14) .

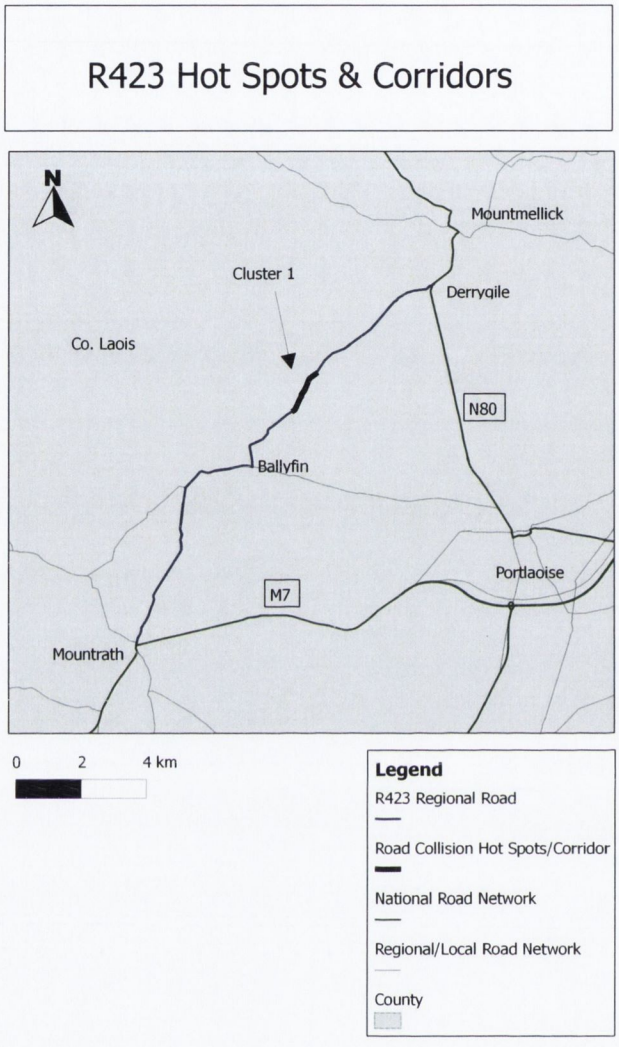

Figure 4.14: R423 Collision Hot Spots/Corridors

- **Cluster 1**
  - Location: Clonygowan, Co. Laois - South West of Esker, Co. Laois
  - Number of collisions: 5
  - Length: 1.3km

Approximately 40% (2/5) of the collisions recorded in cluster 1 were head-on multi-vehicle collisions, 60% (3/5) were single vehicle collisions, 80% (4/5) occurred during the hours of darkness and 80% (4/5) occurred on a weekday. Approximately 60% (3/5) occurred on a dry road surface, zero occurred at a junction and all occurred on sections of road with speed limits 80km/h. Three injuries sustained were minor injuries, four serious injuries and two fatalities were recorded in this cluster.

Table 4.20: R423 Road Collision Hot Spots/Corridors

Description	Cluster 1
Total Number of Collisions	5
Collision Type	
Pedestrian	0
Single Vehicle	3
Head-on	2
Angle	0
Rear-end	0
Unknown	0
Light	
Hours of daylight	1
Hours of darkness	4
Unknown	0
Day	
Weekday	4
Weekend	1
Bank holiday weekend	0
Road Surface	
Dry	3
Wet	2
Other/Unknown	0
Junction	
Yes	0
No	5
Speed Limit	
$\leq$ 60 km/h	0
80km/h	5
100km/h	0

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Table 4.20 – R423 Road Collision Hot Spots/Corridors (contd)

Description	Cluster 1
Injuries	
Fatal	2
Serious	4
Minor	3
Not Injured/Unknown	1

Examination of the seven road traffic collisions recorded on the R423 shows that one collision occurred on the Mountrath to Ballyfin section of the road (Figure4.15) and six collisions occurred on the Ballyfin to R423/N80 junction (Figure 4.16).

Figure 4.15: Road traffic collisions (Mountrath-N80 Jnct)

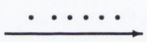

Figure 4.16: Road traffic collisions (Ballyfin-N80 Jnct)

No significant clusters were identified after running the scan on collisions occurring on the section of road running from Ballyfin to R423/N80 junction using a minimum scanning window of 5 (default) or 4 road traffic collisions.

As outlined by Nagarwalla [221] the variable window scan statistic is used to test for a uniform null distribution against an alternative of non-random clustering. Thus the results of the Ballyfin to the N80 junction prompted the examination of the underlying distribution of the 6 road traffic collisions recorded on this section of road.

The Chi-square goodness of fit test was used to determine whether the distribution of collisions on the Ballyfin-N80 junction fit a uniform pattern. The null hypothesis of uniformity was tested against the alternative hypothesis of departure from uniformity. Results from the Chi-square goodness of fit test indicate that null hypothesis was not rejected thus concluding that the road traffic collisions on this section of road are not significantly different from the uniform distribution ($\chi^2 = 5.1675$, degrees of freedom = 5, p-value = 0.3958).

4.8.2 R402 Regional Road

The R402 regional road runs from south of Enfield, Co. Meath to the intersection with regional road R420, south east of Tullamore, Co. Offaly. Eighty three road traffic collisions were recorded on the R402 road from 2005-2009. The scan statistic was run on 83 road traffic collisions. No collisions had geographical coordinates located more than

100m from the R402 road. One cluster was identified in section 1 and Table 4.21 gives detailed description of this cluster. A geographical representation of the cluster can be seen in the map: R402 hot spots and corridors (Figure 4.17).

- **Cluster 1**
  - Location: Dublin Rd, Edenderry, Co. Offaly - St. Mary's Rd, Edenderry, Co. Offaly
  - Number of collisions: 23
  - Length: 1.9km

Approximately 30.4% (7/23) of the collisions recorded in cluster 1 were multi-vehicle collisions, 34.8% (8/23) were pedestrian involved collisions, 95.7% (22/23) occurred during the hours of darkness and 82.6% (19/23) occurred on a weekday. Approximately 39.1% (9/23) occurred on a dry road surface, 17.4% (4/23) occurred at a junction and all occurred on sections of road with speed limits 60km/h or less. Twenty seven injuries sustained were minor injuries, three serious injuries and zero fatalities were recorded in this cluster.

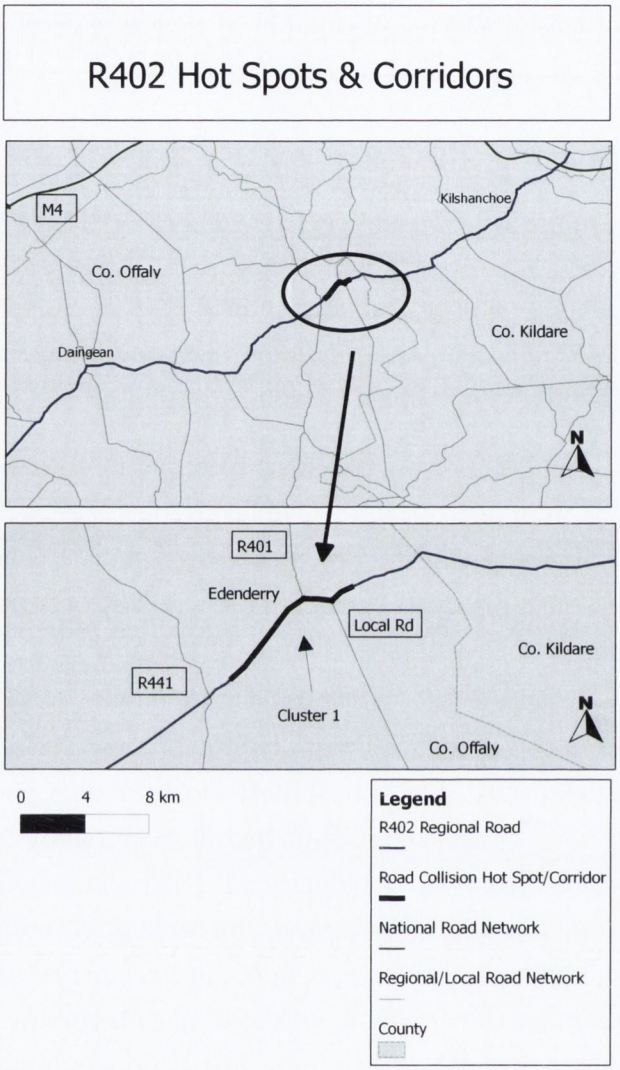

Figure 4.17: R402 Collision Hot Spots/Corridors

Table 4.21: R402 Road Collision Hot Spots/Corridors

Description	Cluster 1
Total Number of Collisions	23
Collision Type	
Pedestrian	8
Single Vehicle	6
Head-on	1
Angle	3
Rear-end	3
Unknown	2
Light	
Hours of daylight	0
Hours of darkness	22
Unknown	1
Day	
Weekday	19
Weekend	3
Bank holiday weekend	1
Road Surface	
Dry	9
Wet	11
Other/Unknown	3
Junction	
Yes	4
No	19
Speed Limit	
$\leq$ 60 km/h	23
80km/h	0
100km/h	0
120km/h	0
Injuries	
Fatal	0
Serious	3
Minor	27
Not Injured/Unknown	2

Comparison of the collision corridor identified via scan statistics and the speed collision prone zone identified by An Garda Síochána indicates that the collision corridor (identified via scan statistics) which is approx. 1.9km in length and contains 23 collisions (three serious injuries and zero fatalities) is incorporated by the 5km speed collision prone zone that was designated by the Gardaí.

4.9 Intersecting Roads

Results from the application of scan statistics to road traffic collisions occurring on national primary, national secondary and regional roads have been outlined in previous sections. An important road characteristic that must be taken into consideration is the application of scan statistics to collisions occurring on intersecting roads.

An Garda Síochána designated a section of the R402 in Edenderry, Co. Offaly as a speed collision prone zone (This zone was also identified by running scan statistics on the R402 road, see section 4.8, p.98). This speed collision prone zone runs on a section of the R402 that incorporates the R401 regional road intersecting the R402 and a local road intersecting the R402 regional road in Edenderry, Co. Offaly.

Using intersecting roads as natural boundaries (as discussed in 3.1.4, p.46) the scan statistic was run on combinations of roads which incorporated the intersection:

- R402 (bounded by regional road R441)/R401 (bounded by local road)
- R402 (bounded by regional road R441)/R402 (bounded by local road intersection)
- R401 (bounded by local road)/R402 (bounded by local road)

The scan producing the maximum lambda was designated as the road collision hot spot/corridor. No significant cluster was identified by taking this approach (i.e. of bounding the roads by local roads).

If the R401 was not bounded by a local road, but was in-fact bounded by regional road R418 and if the R402 (bounded by the R441) / R402 was not bounded by the local road (but instead was bounded by R403), re-running the scan on each of these sections lead to significant clusters being identified. Examination of the (maximum lambda value) cluster characteristics showed that this cluster contained 23 collisions and had a length of 1.9km (same as results from section 4.8, p.98).

Performing a Chi-square test for goodness of fit test ($\chi^2 = 1.75$, degrees of freedom = 15) on collisions recorded in the R402 (bounded by R441) / R402 (bounded by local road) indicates that there is insufficient evidence to reject the null hypothesis of uniformity.

4.10 Summary

This chapter demonstrates the applicability of scan statistics in the identification of road collision hot spots/corridors on national primary, national secondary and regional roads. Initially, temporal scan statistics (Naus' fixed window scan) were applied to all fatal/serious road traffic collisions recorded in the Republic of Ireland from 2005-2009

and scan statistics (Bernoulli model) were applied to all road traffic collisions occurring in cities of Dublin, Cork, Limerick, Galway and Waterford. The primary disadvantages of these scan statistics were the inability to identify the geographical location of the significant clusters and due to the number of consecutive calendar days that had no recorded collisions

Following the application of temporal scan statistics, a space time permutation model was applied to road traffic collisions occurring in Irish cities (Dublin, Cork, Limerick, Galway and Waterford) from 2005-2009. This approach enabled the identification of the temporal and spatial location of the significant cluster. The primary disadvantage of this approach is the inability of this approach to restrict clusters to individual roads in the network, as this approach identifies clusters which span large geographic areas.

A more suitable approach to identify road traffic collision hot spots/corridors along a road network was seen through the Nagarwalla's variable window scan statistic. This approach was used to identify road collision corridors and hot spots on national primary routes as these routes are continuous from beginning to end. Original work by Nagarwalla examined the most likely cluster by extracting a significant cluster based on maximum lambda value, however this did indicate the presence of multiple clusters on the linear network. Thus work on extracting secondary collision hot spots/corridors indicated that the issue of large spanning distances (e.g. a cluster 72km in length), overlapping clusters (e.g. Cluster A finishes in the exact place where cluster B begins) and roll-over clusters (e.g. Cluster a_1 starts within cluster A and finishes within cluster B) could be alleviated by extracting the most likely cluster 'A' (based on Nagarwalla's maximum lambda value approach) and then extending this approach by examining remaining clusters and extracting the next most significant cluster that does not overlap cluster 'A' and select this cluster on its maximum lambda value. This process is repeated until there are no further clusters. This approach was applied to identify road collision hot spots/corridors on the national road network in Ireland.

If the continuity of a road was broken (e.g. national secondary roads are often broken by national primary roads) then adjustments were required which involved these roads being divided into sections (via semantic segmentation) before scan statistics could be applied. Semantic segmentation involved designating road markers, which were bounded by intersection with national primary roads to each national secondary route. Additionally, semantic segmentation based on speed limit zones was applied to the N81 national secondary road and scan statistics were used to identify road collision hot spots/corridors. As the road network is characterised by many intersecting roads, scan statistics with semantic segmentation was also applied to a Garda designated speed collision prone zone on a regional road in Edenderry, Co. Offaly. Findings from this indicated that scan

statistics were able to identify a collision corridor (which fell within the Garda designated zone). A notable finding from the application of scan statistics to identify collision hot spots/corridors occurred when results indicated insufficient evidence to suggest the presence of a collision hot spot/corridor on a section of road, but examining the whole road showed that there was in-fact a hot spot/corridor present. This situation arose when the road traffic collisions were truly uniformly distributed, thus applying scan statistics found insufficient evidence to reject the null hypothesis (of uniformly distributed collisions). This important finding recognises the need for examination of road traffic collisions (via graphical & technical tests (e.g. Chi-square) before applying scan statistics for the detection of collision hot spots/corridors.

Chapter 5

Collision Models

Between 2004 and 2009 (inclusive), 37,150 road traffic collisions, which resulted in at least one fatal/serious/minor injury were recorded in the Republic of Ireland. In order to ascertain the characteristics associated with different types of road traffic collision injuries, general regression models were developed for single vehicle and multi-vehicle collision injuries.* The choice to develop models for single vehicle and multi-vehicle collision injuries separately was based on existing evidence which suggests that the underlying factors for single vehicle and multi-vehicle collisions differ [237]. Based on best practice recommendations [14], the original intention of this research was to apply hierarchical Bayesian regression models to road traffic collision data, however, unfortunately due to poor quality data this could not be achieved. As previously mentioned in Chapter 3, section 3.4.2, age and sex of both drivers and passengers in a collision involving 3 or more vehicles are currently not recorded in the road collision database and road numbers for regional and local roads are also not recorded, thus as a result the development of hierarchical models (of injuries nested within collisions nested within route) was not possible. It is feasible to develop hierarchical regression models for injuries, which occur as a result of collisions involving two vehicles and single vehicle collisions on national roads, as for example injuries nested within collisions nested within national route (e.g. N7, M50, etc.), however, these models would be developed using a small subset of collision data as approximately 74% (27,307/37,150) of all collisions recorded ded between 2004-2009 (inclusive) occurred on regional/local roads, thus developing regression models that specifically examine collision injuries on national primary and secondary routes would not give an overall global model from a national perspective for single vehicle and multi-vehicle collision injuries. In addition to the above limitations, the road traffic collision

*Single vehicle collisions denote collisions involving one vehicle (no pedestrians involved) and multi-vehicle collisions denote (head-on, rear-end and angle) collisions involving two or more vehicles (no pedestrians involved).

data set had a large number of variables that had missing values as for example road markings, weather, seatbelt, drivers license (learners permit or full drivers license).

This Chapter begins with section 5.1, which provides an overview of the data used to develop the global regression models for multi-vehicle and single vehicle collision injuries. Section 5.2 gives an overview of the techniques used in the development of these regression models and sections 5.3-5.4 provide results from the global regression models for both single vehicle and multi-vehicle collisions. Finally, section 5.5 gives a summary of the findings in this chapter.

5.1 Data Overview

Between 2004 and 2009 (inclusive), 37,150 road traffic collisions were recorded in the Republic of Ireland. Approximately 15% (5,554/37,150) of these collisions resulted in at least one fatal/serious injury. Table 5.1 shows the counts of the road traffic collisions per year. Examination of these counts indicate a decreasing trend in the number of fatal/serious collisions and an oscillating trend for minor collisions from 2004-2009.

Table 5.1: Road Collision Data 2004-2009

Year	All Collisions	Fatal/Serious Collisions	Minor Collisions
2004	5781	985 (17.0%)	4796 (83.0%)
2005	6533	1126 (17.2%)	5407 (82.8%)
2006	6018	974 (16.2%)	5044 (83.8%)
2007	5467	925 (16.9%)	4542 (83.1%)
2008	6736	862 (12.8%)	5874 (87.2%)
2009	6615	682 (10.3%)	5933 (89.7%)

Table 5.2 shows the different types of collisions recorded from 2004-2009. Single vehicle collisions account for 22% (8,267/37,150), head-on collisions account for 17% (6,276/37,150), pedestrian involved collisions account for 16% (5835/37,150) and rear-end collisions account for 15% (5,632/37,150). Unfortunately, a large number of collisions (28%; (10,670/37,150)) are unknown.

Table 5.2: Collision Type 2004-2009

Type	2004 N=5781	2005 N=6533	2006 N=6018	2007 N=5467	2008 N=6736	2009 N=6615
Pedestrian	918 (15.9%)	880 (13.5%)	924 (15.4%)	934 (17.1%)	1108 (16.4%)	1071 (16.2%)

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Table 5.2 – Collision Type 2004-2009

Type	2004	2005	2006	2007	2008	2009
Single vehicle	1218	1234	1383	933	1719	1780
	(21.1%)	(18.9%)	(23.0%)	(17.1%)	(25.5%)	(26.9%)
Head-on	1130	1431	1136	849	933	797
	(19.5%)	(21.9%)	(18.9%)	(15.5%)	(13.9%)	(12.0%)
Angle	988	1116	985	742	708	499
	(17.1%)	(17.1%)	(16.4%)	(13.6%)	(10.5%)	(7.5%)
Rear-end	877	1031	896	792	975	1061
	(15.2%)	(15.8%)	(14.9%)	(14.5%)	(14.5%)	(16.0%)
Unknown	1865	2147	1881	1534	1683	1560
	(32.3%)	(32.9%)	(31.3%)	(28.1%)	(25.0%)	(23.6%)

Global regression models developed in this study used road traffic collision injury data based on collision type, thus the data used to create single vehicle models is collision data where collision type is classified as 'single vehicle' and data to create multi-vehicle models are data where collision type is classified as 'head-on, angle or rear-end' collisions and the number of vehicles involved is 2 or more vehicles*. It is recognised that a large number of collisions are unknown, however, as this research focuses on collision injuries based on collision type, these unknown collisions could not be classified as single vehicle or multi-vehicle collisions, thus as a result these collisions were not used to develop global regression models in this research.

Single Vehicle Collisions 2004-2009

Single vehicle collisions account for 22% (8267/37150) of all recorded collisions between 2004-2009 (inclusive). Examining single vehicle collisions indicates that the most frequently occurring collision involved crashing into a ditch - accounting for 43% (3510/8267). Collisions involving an inanimate object e.g. wall/ pole/bollard etc.. - accounted for 33% (2707/8267).Approximately 72% (6001/8267) of all single vehicle collisions occur on regional/local routes. Approximately 19% (1596/8267) of single vehicle collisions resulted in at least one fatal/serious injury.

Table 5.3 provides a descriptive overview of single vehicle traffic collisions. This table is based on a complete data set* of 6,199 single vehicle road traffic collisions. Examination of single vehicle collisions indicate that approximately 63% (3931/6199) were 'driver-only' and 37% (2268/6199) were 'driver +' collisions.‡

*There are a number of instances in the road collision data set where the number of vehicles involved in a collision e.g. head-on collision is 1, thus to examine multi-vehicle collisions, any entry where the number of vehicles is less than two were not used to develop multi-vehicle collision models

*Complete data set denotes a data set where all missing values have been excluded

‡Driver + denotes driver with at least one passenger in the vehicle

Table 5.3: Single vehicle collisions characteristics 2004-2009

Coefficient	Driver only Fatal/Serious N=714	Driver only Minor N=3217	Driver + Fatal/Serious N=536	Driver + Minor N=1732
Light				
Daylight	227	788	224	563
	(31.8%)	(24.5%)	(41.8%)	(32.5%)
Dark (with lighting)	140	526	124	321
	(19.6%)	(16.4%)	(23.1%)	(18.5%)
Dark	347	1903	188	848
	(48.6%)	(59.1%)	(35.1%)	(49.0%)
Day				
Week day	380	2049	262	969
	(53.2%)	(63.7%)	(48.9%)	(55.9%)
Weekend	296	1070	245	701
	(41.5%)	(33.3%)	(45.7%)	(40.5%)
Public/Bank holiday	38	98	29	62
weekend	(5.3%)	(3.0%)	(5.4%)	(3.6%)
Road Type				
National Secondary Rd	76	346	73	188
	(10.6%)	(10.8%)	(13.6%)	(10.9%)
National Primary Rd	118	552	85	271
	(16.6%)	(17.2%)	(15.9%)	(15.6%)
Regional/local Rd	520	2319	378	1273
	(72.8%)	(72.0%)	(70.5%)	(73.5%)
Road Surface				
Dry	422	1610	317	819
	(59.1%)	(50.0%)	(59.2%)	(47.3%)
Wet	255	1313	198	761
	(35.7%)	(40.9%)	(36.9%)	(43.9%)
Other (e.g. frost/ice)	37	294	21	1521
	(5.2%)	(9.1%)	(3.9%)	(8.8%)
Speed Limit				
50km/h	128	594	101	346
	(17.9%)	(18.5%)	(18.8%)	(20.0%)
60km/h	38	186	17	84
	(5.3%)	(5.8%)	(3.2%)	(4.8%)
80km/h	305	1361	239	793
	(42.7%)	(42.3%)	(44.6%)	(45.9%)
100km/h	234	1015	174	484
	(32.8%)	(31.6%)	(32.5%)	(27.9%)
120km/h	9	61	5	25
	(1.3%)	(1.8%)	(0.9%)	(1.4%)

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Table 5.3 – Single vehicle collisions characteristics 2004-2009 contd.

Coefficient	Driver only Fatal/Serious N=714	Driver only Minor N=3217	Driver + Fatal/Serious N=536	Driver + Minor N=1732
Junction				
No	649	2938	484	1540
	(90.9%)	(91.3%)	(90.3%)	(88.9%)
Yes	65	279	52	192
	(9.1%)	(8.7%)	(9.7%)	(11.1%)
Vehicle Type				
Car	486	2501	463	1539
	(68.1%)	(77.7%)	(86.4%)	(88.9%)
Goods	66	328	39	135
	(9.2%)	(10.2%)	(7.3%)	(7.8%)
PSV (e.g. bus)	3	9	6	15
	(0.4%)	(0.3%)	(1.1%)	(0.9%)
Motor Cycle	126	286	19	18
	(17.7%)	(8.9%)	(3.5%)	(1.0%)
Other	33	93	9	25
	(4.6%)	(2.9%))	(1.7%)	(1.4%)
Road:				
Straight	320	1551	257	808
	(44.8%)	(48.2%)	(48.0%)	(46.7%)
Bend	274	1345	223	746
	(38.4%)	(41.8%)	(41.6%)	(43.1%)
Gradient/Hill Crest	92	262	43	149
	(12.9%)	(8.2%)	(8.0%)	(8.6%)
Other	28	59	13	29
	(3.9%)	(1.8%)	(2.4%)	(1.6%)
Time of day				
Peak 7am-10am,4pm-7pm	189	988	75	403
	(26.5%)	(30.7%)	(14.0%)	(23.3%)
Off-peak 10am-4pm,7pm-12pm	302	1452	216	823
	(42.3%)	(45.1%)	(40.3%)	(47.5%)
Night 12pm-7am	223	777	245	506
	(31.2%)	(24.2%)	(45.7%)	(29.2%)
Collision involving				
Object e.g. wall/pole	311	939	242	574
	(43.6%)	(29.2%)	(45.1%)	(33.1%)
Animal	8	78	10	29
	(1.1%)	(2.4%)	(1.9%)	(1.7%)
Parked vehicle	16	124	13	57
	(2.2%)	(3.9%)	(2.4%)	(3.3%))

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Table 5.3 – Single vehicle collisions characteristics 2004-2009 contd.

Coefficient	Driver only Fatal/Serious N=714	Driver only Minor N=3217	Driver + Fatal/Serious N=536	Driver + Minor N=1732
Ditch	250	1509	194	806
	(35.0%)	(46.9%)	(36.2%)	(46.5%)
Other	129	567	77	266
	(18.1%)	(17.6%)	(14.4%)	(15.4%)
Driver Age				
25 years or less	273	1103	323	834
	(38.2%)	(34.3%)	(60.3%)	(48.1%)
26-39 years	252	1181	126	520
	(35.3%)	(36.7%)	(23.5%)	(30.0%)
40-64 years	157	742	72	325
	(22.0%)	(23.1%)	(13.4%)	(18.8%)
65+ years	32	191	15	53
	(4.5%)	(5.9%)	(2.8%)	(3.1%)
Driver Sex				
Female	143	1102	89	533
	(20.0%)	(34.3%)	(16.6%)	(30.8%)
Male	571	2115	447	1199
	(80.0%)	(65.7%)	(83.4%)	(69.2%)

Driver + denotes driver with at least one passenger in the vehicle

Approximately 18% (714/3931) of these 'driver-only' collisions resulted in a fatal/serious injury. Fatal/serious 'driver-only' collisions most frequently occurred during the hours of darkness 68%(487/714); 47% (334/714) occurred at weekends or public/bank holiday weekends and 73% (520/714) occurred on regional/local roads. Approximately 44% (311/714) of fatal/serious 'driver-only' single vehicle collisions involved crashing into a man-made object e.g. wall, pole or bollard etc.. and 35% (250/714) involved crashing into a ditch. Approximately 76% (539/714) of fatal/serious 'driver-only' collisions occurred on roads with a speed limit of 80km/h or 100km/h.

Single vehicle 'driver with passengers' collisions account for 37% (2268/3931) of all single vehicle collisions. Approximately, 31% (536/1732) of these collisions result in at least one fatal/serious injury. Fifty one percent (274/536) of these fatal/serious 'driver with passengers' collisions occurred at weekends/bank holiday weekends; 45% (242/536) involved colliding with a mad-made object and 58% (312/536) occurred during the hours of darkness. Fatal/serious 'driver with passenger' collisions most frequently occurred on regional/local roads - 71% (378/536). Approximately 77% (413/536) of fatal/serious

collisions occurred on roads with a speed limit of 80km/h or 100km/h.

Approximately 81% (1018/1250) of all fatal/serious single vehicle collisions involved male drivers. Table 5.4 shows counts per age-groups for both male and female drivers involved in 'driver-only' and 'driver with passengers' single vehicle collisions.

Table 5.4: Human characteristics (single vehicle collisions 2004-2009)

Age	Driver only Fatal/Serious	Driver only Minor	Driver + Fatal/Serious	Driver + Minor
Male Driver	**N=571**	**N=2115**	**N=447**	**N=1199**
25 years or less	225	729	280	620
	(39.4%)	(34.5%)	(62.6%)	(51.7%)
26-39 years	208	803	102	328
	(36.4%)	(38.0%)	(22.8%)	(27.4%)
40-64 years	114	464	57	217
	(20.0%)	(21.9%)	(12.8%)	(18.1%)
65+ years	24	119	8	34
	(4.2%)	(5.6%)	(1.8%)	(2.8%)
Female Driver	**N=143**	**N=1102**	**N=89**	**N=533**
25 years or less	48	374	43	214
	(33.6%)	(33.9%)	(48.3%)	(40.2%)
26-39 years	44	378	24	192
	(30.8%)	(34.3%)	(27.0%)	(36.0%)
40-64 years	43	278	15	108
	(30.1%)	(25.2%)	(16.9%)	(20.3%)
65+ years	8	72	7	19
	(5.6%)	(6.5%)	(7.9%)	(3.6%)

Driver+ denotes driver with at least one passenger in the vehicle

Multi-vehicle Collisions 2004-2009

Multi-vehicle collisions* account for 44% (16145/37150) of all recorded collisions between 2004-2009 (inclusive). Examination of multi-vehicle collisions indicate that collisions involving 2-vehicles account for 86% (13878/16145) of all multi-vehicle collisions. Approximately 69% (11134/16145) of all multi-vehicle collisions occur on regional/local routes. Fatal/serious multi-vehicle collisions account for 12.5% (2017/16145) of all multi-vehicle collisions.

Table 5.5 provides a descriptive overview of multi-vehicle road traffic collisions. This table is based on a complete data set of 11,187 multi-vehicle road traffic collisions.

*Multi-vehicle collisions denote collisions which are classified as head-on, angle or rear-end collisions and involve 2 or more vehicles in the collision

Table 5.5: Collision characteristics (multi-vehicle collisions 2004-2009)

Coefficient	2-vehicle Fatal/Serious N=1324	2-vehicle Minor N=8300	3+ vehicle Fatal/Serious N=175	3+ vehicle Minor N=1388
Light				
Daylight	235	746	32	88
	(17.7%)	(9.0%)	(18.3%)	(6.3%)
Dark (with lighting)	169	1463	14	209
	(12.8%)	(17.6%)	(8.0%)	(15.1%)
Dark	920	6091	129	1091
	(69.5%)	(73.4%)	(73.7%)	(78.6%)
Day				
Week day	868	6063	118	1045
	(65.6%)	(73.0%)	(67.4%)	(75.3%)
Weekend	412	2033	48	313
	(31.1%)	(24.5%)	(27.4%)	(22.6%)
Public/Bank holiday	44	204	9	30
weekend	(3.3%)	(2.5%)	(5.1%)	(2.1%)
Road Type				
National Secondary Rd	171	796	21	186
	(12.9%)	(9.6%)	(12.0%)	(13.4%)
National Primary Rd	350	1476	80	453
	(26.4%)	(17.8%)	(45.7%)	(32.6%)
Regional/local Rd	803	6028	74	749
	(60.7%)	(72.6%)	(42.3%)	(54.0%)
Road Surface				
Dry	799	4836	116	807
	(60.4%)	(58.3%)	(66.3%)	(58.1%)
Wet	489	3207	52	542
	(36.9%)	(38.6%)	(29.7%)	(39.1%)
Other (e.g. frost/ice)	36	257	7	39
	(2.7%)	(3.1%)	(4.0%)	(2.8%)
Speed Limit				
50km/h	230	3291	22	523
	(17.4%)	(39.7%)	(12.6%)	(37.7%)
60km/h	77	629	9	117
	(5.8%)	(7.7%)	(5.1%)	(8.4%)
80km/h	441	2311	47	268
	(33.3%)	(27.8%)	(26.9%)	(19.3%)
100km/h	563	2014	94	440
	(42.5%)	(24.3%)	(53.7%)	(31.7%)
120km/h	13	55	3	40
	(0.98%)	(0.7%)	(1.7%)	(2.9%)

Continued on next page

Table 5.5 – Multi-Vehicle Road Traffic Collisions 2004-2009 contd.

Coefficient	2-vehicle Fatal/Serious N=1324	2-vehicle Minor N=8300	3+ vehicle Fatal/Serious N=175	3+ vehicle Minor N=1388
Junction				
No	1005	5186	137	1016
	(75.9%)	(62.5%)	(78.3%)	(73.2%)
Yes	319	3114	38	372
	(24.1%)	(37.5%)	(21.7%)	(26.8%)
Road:				
Straight	718	5393	109	1052
	(54.2%)	(65.0%)	(61.3%)	(75.8%)
Bend	371	1744	42	138
	(28.0%)	(21.0%)	(24.0%)	(9.9%)
Gradient/Hill Crest	202	943	18	181
	(15.3%)	(11.4%)	(10.3%)	(13.0%)
Other	33	220	6	17
	(2.5%)	(2.7%)	(3.4%)	(1.3%)
Collision Type:				
Head-on	843	2963	110	281
	(63.7%)	(35.7%)	(62.9%)	(20.2%)
Angle	324	2763	18	145
	(24.5%)	(33.3%)	(10.3%)	(10.5%)
Rear-end	157	2574	47	962
	(11.86%)	(31.0%)	(26.9%)	(69.3%)

3+ denotes 3 or more vehicles

Examination of multi-vehicle collisions indicate that approximately 86% (9624/11187) were '2-vehicle' collisions. Approximately 14% (1324/9624) of these '2-vehicle' collisions resulted in at least one fatal/serious injury. Fatal/serious '2-vehicle' collisions most frequently occurred during the hours of darkness 82.3% (1089/1324); 65.6% (868/1324) occurred on a weekday and 60.7% (803/1324) occurred on regional/local roads. Sixty percent (799/1324) occurred on a dry road surface, 54.2% (718/1324) of fatal/serious '2-vehicle' collisions occurred on straight sections of road and 24.1% (319/1324) occurred at a junction. Approximately 63.7% (843/1324) of fatal/serious '2-vehicle' collisions were head-on collisions and 75.8% (1004/1324) occurred on roads with a speed limit of 80km/h or 100km/h. In contrast 64.3% (5337/8300) of '2-vehicle' collisions (where at least one minor injury was sustained) were rear-end/angle collisions. Approximately 69% (13264/19248) of all drivers involved in '2-vehicle' collisions were male drivers and approximately 77.7% (2058/2648) of drivers involved in fatal/serious '2-vehicle' collisions were male drivers. Table 5.6 shows counts per age-groups for both male and female

drivers involved in fatal/serious and minor '2-vehicle' collisions.

Table 5.6: Human characteristics (multi-vehicle collisions 2004-2009)

Age	2-vehicle Fatal/Serious	2-vehicle Minor
Male Driver	**N=2058**	**N=11206**
25 years or less	537	2930
	(26.1%)	(26.2%)
26-39 years	717	3882
	(34.8%)	(34.6%)
40-64 years	661	3689
	(32.1%)	(32.9%)
65+ years	143	705
	(6.9%)	(6.3%)
Female Driver	**N=590**	**N=5394**
25 years or less	138	1257
	(23.3%)	(23.3%)
26-39 years	193	2017
	(32.7%)	(37.4%)
40-64 years	205	1811
	(34.7%)	(33.6%)
65+ years	54	309
	(9.1%)	(5.7%)

Examination of Table 5.5 shows that multi-vehicle collisions involving three or more vehicles (3+) account for 14% (1563/11187). Approximately 11% (175/1563) of these collisions resulted in at least one fatal/serious injury. Fatal/serious '3+ vehicle' collisions most frequently occurred during the hours of darkness 81.7% (141/175); 67.4% (118/175) occurred on a weekday and 42.3% (74/175) occurred on regional/local roads and 45.7% (80/175) occurred on national primary roads. Sixty six percent (116/175) occurred on a dry road surface, 61.3% (109/175) of fatal/serious '3+ vehicle' collisions recorded occurred on straight sections of road and 21.7% (38/175) occurred at a junction. Approximately 62.9% (110/175) of fatal/serious '3+ vehicle' collisions were head-on collisions and 80.5% (141/175) occurred on roads with a speed limit of 80km/h or 100km/h. In contrast 79.8% (1107/1388) of '3+ vehicle' collisions (where at least one minor injury was sustained) were rear-end/angle collisions.

5.2 Global Models

As previously mentioned, the original intention of this research was to apply hierarchical Bayesian regression models to road traffic collision injury data, however, unfortunately due to poor quality data this could not be achieved. Thus in this research, the global regression models developed from the Bayesian perspective produce the exact same results as frequentist models because non-informative priors have been used in the Bayesian models.

Regression models were developed using road traffic collision data recorded from 2004-2008 and collision data recorded in 2009 were used to evaluate these models. The models developed in this research were based on collision type:

- Single vehicle collisions
  - Binomial regression model - focused on the counts of all fatal/serious injuries as a proportion of all persons involved in a single vehicle collision.
  - Logistic regression model was applied to 'driver-only' collision data i.e. the driver was the only occupant of the vehicle involved in the single vehicle collision.
- Multi-vehicle collisions
  - Binomial regression model - focused on the counts of all fatal/serious injuries as a proportion of all persons involved in multi-vehicle collisions.

Explanatory factors in these models were broadly classified as human, vehicle, environmental and road geometry (see Table 5.7 and corresponding definitions are given in Appendix).

Table 5.7: Model Factors

Factor	Description
Outcome	Fatal/serious injury, Other injury
Gender	Female, Male
Age	<25yrs, 26-39yrs, 40-64yrs, 65+yrs
Vehicle occupants	Driver only; Driver with passengers
Vehicle type	Car, Goods, Motor Cycle, PSV, Other
Day	Weekday, Weekend, Bank holiday weekend/Public holiday
Road surface	Dry, Wet, Other (e.g. frost/ice/snow)
Light	Day light; Dark with street lights, Dark
Speed Limit	50km/h, 60km/h, 80km/h, 100km/h, >100km/h

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Table 5.7 – Model Factors contd.

Factor	Description
Road Geometry	Straight, bend, hill crest, gradient, other
Collision at junction	No, Yes
Time of day	Peak 7am-10am,4pm-7pm; Off-peak 10am-4pm,7pm-12pm; Night 12pm-7am
Single vehicle collision type	Object e.g. wall/pole/bollard; Parked vehicle
	Animal, Ditch, Other
Multi-vehicle collision type	Head-on, angle, rear-end

In advance of reporting the results obtained from the regression models in this research, this sub-section will provide a brief introduction to the models developed for both single vehicle and multi-vehicle collision injury data.

Generalised Linear Regression Models

In this research, regression models were used to model binary (0,1) road traffic collision injury data e.g. fatal/serious injury (success) or minor injury (failure). A logistic regression model was developed for single vehicle (driver only) collision injuries where a success denoted a fatal/serious injury and a failure denoted a minor injury. In the single vehicle (driver-only) data set, only one injury occurred per collision as the driver was the only occupant in the vehicle. Binomial regression models focused on the counts of all fatal/serious injuries as a proportion of all persons involved in a single vehicle collision or in a multi-vehicle collision e.g. 5 persons involved in a collision - 2 persons out of a total of 5 persons were fatally/seriously injured and 3 persons out of 5 sustained minor injuries in the collision. Although the responses in these models were accumulated to provide the number of fatal/serious injuries (successes) and the number of minor injuries (failures), the binary nature (fatal/serious injury versus minor injury)of the response still remains.

Generalised linear models extend ordinary (normal) linear regression models and are based on the exponential family of distributions. This family of distributions encompass the normal, binomial and Poisson distributions. Generalised linear models consist of three components: a random component (or stochastic component), a systematic component and a link function

- *Random component* identifies the response variable Y_i and its probability distribution
- A *systematic component* specifies the explanatory variables (or covariates) used in a linear predictor function
- The *link function* connects the parameters of the response Y with the linear predictor and the covariates

With specific reference to road traffic collisions: let $y_1, y_2, y_3, ..., y_n$ denote injuries sustained in n road traffic collisions such that the probability of a fatal/serious injury ("success") is $P(Y_i = 1) = \pi$ and the probability of a minor injury ("failure") is $P(Y_i = 0) = 1 - \pi$, The total number of fatal/serious injuries $Y = \sum_{i=1}^{n} Y_i$ has the binomial distribution with index n and parameter π i.e. $bin(n, \pi)$

The probability mass function for the possible outcomes (injuries) y for Y is:

$$p(y) = \begin{pmatrix} n \\ y \end{pmatrix} \pi^y (1 - \pi)^{n-y} \tag{5.1}$$

where $y = 1, 2, ...n$ and the binomial co-efficient in equation 5.1 is

$$\begin{pmatrix} n \\ y \end{pmatrix} = \frac{n!}{y!(n - y)!} \tag{5.2}$$

The binomial distribution for $Y = \sum_{i=1}^{n} Y_i$ has mean $\mu = E(Y) = n\pi$ and variance $\sigma^2 = var(Y) = n\pi(1 - pi)$

If the response variable Y takes values from zero to n, $y \in (0, 1, 2, ...n)$ the binomial distribution with success probability π and n repetitions is considered. With reference to road traffic collision models - the binomial model for multi-vehicle collision injuries focused on the counts of all fatal/serious injuries as a proportion of all persons involved in a multi-vehicle collision, e.g. 2 persons out of a total of 4 persons were fatally/seriously injured in a multi-vehicle collision.

In the case of binary data $y \in [0, 1]$ the Bernoulli distribution is equal to a binomial distribution with $n = 1$. With reference to the model for single vehicle driver-only collision injuries - each observation has one of two outcomes, denoted by 0 or 1, which is binomial for a single trial e.g. a driver is either fatal/seriously injured (denoted as 1) or he/she has a minor injury (denoted as 0). The canonical link models the log-odds of success as linear combination of the covariates - this link is the logit function $log((\pi)/(1 - \pi))$.

Interpretation of model parameters in binomial response models

Model interpretation given in this section is based on the description given by Ntzoufras[238]

The logistic model can be written as $Y_i \sim binomial\ (\frac{\pi}{1-\pi}, N_i)$

$$log(\frac{\pi_i}{1 - \pi_i}) = \beta_0 + \sum_{j=1}^{p} \beta_j x_{ij} = X_{(i)}\beta \tag{5.3}$$

The probability of success can be calculated by using the odds: $(\frac{\pi}{1-\pi})$ e.g. If the odds

= 4, this implies that the success probability (e.g. fatal/serious injury probability) is four times as high as the failure probability (e.g. minor injury probability) whereas odds = 0.2 implies that the success probability (e.g. fatal/serious injury probability) is 20% of the failure probability [†]

The odds ratio (OR) denotes the ratio of the two odds of two different outcomes. ORs give the relative change of the odds under two different conditions. If the value of OR = 1, indicates that there is no difference in the relative probability of Y under the two outcomes.

For a logistic regression model with one arithmetic covariate the OR denotes the relative odds magnitude when X increases by one unit

$$log(odds(x)) = \beta_0 + \beta_1 x \tag{5.4}$$

$$odds = exp\beta_0 + exp\beta_1 \tag{5.5}$$

$$OR_{x+1,x} = \frac{odds(x+1)}{odds(x)} = exp\beta_1 \tag{5.6}$$

If X is a categorical variable with K levels e.g. X=sex of driver and K=2 levels (female(level 1) or male (level 2)), then the first level is used a baseline/reference group e.g. OR = 3: the fatal/serious injury odds are 3 times as high for male drivers as the corresponding odds for female drivers

The interpretation of multiple logistic regression models is easily extended - the ORs are reported as "odds ratios adjusted for the other covariates or odds ratios after controlling for the effect of other covariates"[238]

Bayesian versus Frequentist (classical) perspective

Without delving into probability theory and mathematical statistics - this section provides a brief outline of the different perspectives of Bayesian and classical statistics. The main difference between both approaches is that Bayesians consider parameters as random variables that are characterised by a prior distribution. Combining the prior distribution and traditional likelihood, results in a posterior distribution of the parameter of interest on which the

[†]To calculate the percentage increase or decrease of the success probability to the corresponding failure probability, the formula $(odds - 1) * 100$ must be applied. A negative value indicates a decrease and a positive value indicates an increase e.g. odds = 0.2, this implies that the probability of success is 80% lower than the probability of failure.

statistical inference is based [238].

From the Bayesian perspective "Any quantity for which the true value is uncertain, including model parameters, can be represented with probability distributions" [239] however from the frequentist perspective "it is unacceptable to place probability distributions on parameters, because parameters are assumed to be fixed quantities: only the data are random, and thus probability distributions can only be used to represent data" [239]

- **Bayesian**: model parameters are considered random and observed data are considered as fixed
- **Frequentist**: model parameters are considered as fixed and observed data are considered as random

As previously mentioned, the original intention of this research was develop hierarchical Bayesian regression models to road traffic collision injury data but unfortunately, due to poor quality data, it was not possible to develop these models. Bayesian models developed in this research produce the exact same results as frequentist models because non-informative priors based on the normal distribution have been used in the Bayesian models. Global regression models developed in this research include: Binomial regression models for injuries as a result of single vehicle collisions (with passengers) and multi-vehicle collisions and a logistic regression model was developed for single vehicle (driver-only) collision injuries. Corresponding code used to develop each of these models in this research is provided in the appendix.

5.2.1 Diagnostics

In order to check model convergence, a number of diagnostic tests were used via the Coda package in statistical software R*

- Visual inspection of density and trace plots
  - A trace plot is used to plot the iteration number against the value of the collision injury of the variable at each iteration and a density plot is used to plot a density estimate for each variable in the chain

*The description of each diagnostic test outlined in the test are based on the descriptions given in the corresponding documentation for the coda package
http://cran.r-project.org/web/packages/coda

- Autocorrelation plots
  - An autocorrelation plot is used to plot the autocorrelation function for each variable in the chain. The autocorrelation function measures the correlation between variable x_1 and each x_{k+1} variables in the chain. High autocorrelations within chains indicate slow mixing, and usually slow convergence, thus it may be useful to thin out a chain under these circumstances[†]
- Geweke's convergence diagnostic
  - This convergence diagnostic, proposed by Geweke [240] is used to test for equality of means of the first and last part of the chain (first 10% and last 50% by default in coda package) Asymptotically, the Geweke statistic has a standard normal distribution, thus the test statistic is the standard Z-score. If the output from R gives values greater than 2.5 or less than -2.5, this indicates non-stationarity of the chain and the burn-in is insufficient[‡]

Caterpillar Plots

Caterpillar plots were created using the mcmcplots package in statistical software R[§]. Caterpillar plots are plots of credible intervals for parameters from an MCMC simulation. The outer element of the caterpillar plot contains the 95% credible intervals of the posterior draws, which are plotted as the longer, thinner line. The inner element of the caterpillar plot contain the 68% credible intervals of the posterior draws, which are plotted as the shorter, thicker line.

Model evaluation

Receiver-operating characteristic (ROC) plots and area-under-curve (AUC) have been used to evaluate 'driver-only' and 'driver with passengers' models. As described by [241]. A ROC plot shows the sensitivity (the proportion of positive observations correctly classified) and specificity (the proportion of negative observations correctly classified) as the output threshold is moved over the range all possible values. ROC curves are empirical curves in the sensitivity and specificity space. Trapezoids are used to compute AUCs and corresponding confidence intervals are calculated using Delong's method. A more detailed explanation can be found in [242]. Perfect discrimination can be identified when the ROC plot passes through the upper left corner, where the true-positive fraction is

[†]A thinning interval or sampling lag is chosen to allow an independent sample to be produced.

[‡]A Burn-in period is the period where the first B iterations are eliminated from the sample to avoid the influence of the initial values

[§]http://cran.r-project.org/web/packages/mcmcplots

1.0 or 100% (perfect sensitivity), and the false-positive fraction is 0 (perfect specificity). A ROC plot showing no discrimination is a 45 degree diagonal line from the lower left corner to the upper right corner [243].

In this research, ROC plots and AUC were used to validate model performance on the collision data (2004-2008) used to develop the binomial and logistic models and also validate model performance using different collision data (2009).

5.2.2 Software

Data were analysed using the statistical software packages JMP (version 7, 2007, SAS Corp) for data management, R (version 2.12.2, R CORE TEAM, 2011) and JAGS (version 2.2.0, 2010)

5.3 Results: Single Vehicle Collision Injuries

Tables 5.8 and 5.11 show results obtained from Bayesian logistic model(L) and Bayesian Binomial model(B) produced for fatal/serious injuries for 'driver-only' and 'driver with passengers' single vehicle collisions (2004-2008). Conditional on a single vehicle collision occurring, model results indicate that differences and similarities exist between outcomes for 'driver-only' and 'driver with passengers' collisions.

Statistically significant variables for single vehicle 'driver only' collisions include collision type, light, public/bank holiday weekend, road surface, road geometry, speed limit and driver sex. There was insufficient evidence to suggest that driver age, time of day, junction and road type and any interactions were significant.

5.3.1 Single vehicle 'driver only' collision injuries (2004-2008)

Conditional on a single vehicle 'driver only' collision occurring, results in this section are the odds ratios (O.R.) and corresponding 95% credible interval (95% C.I.) after controlling for the effect of other covariates (see Table 5.8).

Single vehicle 'driver only' collisions occurring during the hours of darkness[†] were less likely to contain a fatal/serious injury than 'driver only' collisions occurring during the hours of daylight (O.R. 0.61; 95% C.I.(0.49,0.77)) and collisions occurring on a wet road surface as opposed to a dry road surface were also less likely to result in a fatal/serious injury (O.R. 0.8; 95% C.I.(0.65,0.98)). Single vehicle 'driver only' collisions occurring on a public/bank holiday weekend were more likely to result in a fatal/serious injury than 'driver only' collisions occurring on a week day (O.R. 1.65, 95% C.I.(1.10,2.49)).

[†]Hours of darkness is defined as 30 minutes before sunrise and 30 minutes after sunset

Examination of vehicle type indicates that single vehicle 'driver only' motorcycle collisions were more likely to result in a fatal/serious injury than a single vehicle 'driver only' car collision (O.R. 2.45; 95% C.I.(1.84,3.27)). Driver only collisions occurring on roads with a speed limit of 80km/h (O.R. 1.59, 95% C.I. (1.19,2.13)) or 100km/h (O.R. 1.47, 95% C.I. (1.09,1.97)) were more likely to contain a fatal/serious injury than collisions occurring on roads with a speed limit of 50km/h. Single vehicle 'driver only' collisions occurring on a hill/gradient were more likely to result in a fatal/serious injury than collisions occurring on a straight section of road (O.R. 1.37, 95% C.I.(1.02,1.85)). Male drivers involved in a single vehicle 'driver only' collision were more likely to sustain a fatal/serious injury than female drivers (O.R. 1.49; 95% C.I. (1.18,1.89)).

Figure 5.1 shows a caterpillar plot of odds for fatal/serious single vehicle 'driver only' collision injuries.

Table 5.8: Odds of fatal/serious injuries: 'driver-only' single vehicle collisions (2004-2008)

Coefficient	Odds Ratio	(95% C.I.)
Intercept	0.25	(0.17,0.37)
Light		
Daylight	-	-
Dark (with lighting)	0.76	(0.57,1.02)
Dark	0.61	(0.49,0.77)
Day		
Week day	-	-
Weekend	1.14	(0.93,1.38)
Public/Bank holiday weekend	1.65	(1.10,2.49)
Road Surface		
Dry	-	-
Wet	0.8	(0.65,0.98)
Other (e.g. frost/ice)	0.6	(0.4,0.92)
Speed Limit		
50km/h	-	-
60km/h	1.04	(0.65,1.67)
80km/h	1.59	(1.19,2.13)
100km/h	1.47	(1.09,1.97)
120km/h	1.49	(0.67,3.28)
Vehicle Type		
Car	-	-
Goods	1.02	(0.74,1.41)
PSV (e.g. bus)	1.72	(0.43,6.86)
Motor Cycle	2.45	(1.84,3.27)
Other	2.03	(1.29,3.18)

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Table 5.8 –Odds of fatal/serious injuries single vehicle collisions 2004-2008 contd.

Coefficient	Odds Ratio	(95% C.I.)
Road:		
Straight	-	-
Bend	0.89	(0.72,1.09)
Gradient/Hill Crest	1.37	(1.02,1.85)
Other	2.03	(1.19,3.48)
Collision involving		
Object e.g. wall/pole	-	-
Animal	0.47	(0.25,0.87)
Parked vehicle	0.19	(0.08,0.43)
Ditch	0.48	(0.38,0.59)
Other	0.63	(0.48,0.83)
Sex		
Female	-	-
Male	1.49	(1.18,1.89)

Predicted Probability: Fatal/Serious Single Vehicle Driver Only Collision Injuries (2004-2008)

Predicted probabilities* of fatal/serious injuries as a result of a single vehicle driver only collision occurring in a number of different scenarios† are given as follows:

- **Scenario:** collision involving a car, during daylight hours, on a straight section of road, on a weekday, dry road surface, crashing into a wall/pole
  - Female driver, road speed limit of 50km/h‡:
    Predicted probability = 0.20; 95% C.I.(0.14,0.27)
  - Female driver, road speed limit of 100km/h:
    Predicted probability = 0.27; 95% C.I.(0.15,0.43)
  - Male driver, road speed limit of 50km/h:
    Predicted probability = 0.27; 95% C.I.(0.16,0.41)
  - Male driver, road speed limit of 100km/h:
    Predicted probability = 0.35; 95% C.I.(0.18,0.59)

*Predicted probability = (odds/(1+odds))

†Examination of the caterpillar interval plot (Figure 5.1) shows that the scenarios given in the text give a range of conditions that produce high predicted probabilities and low predicted probabilities for fatal/serious single vehicle driver only collision injuries

‡This single vehicle driver only scenario for a female driver, road speed limit of 50km/h denotes the model intercept

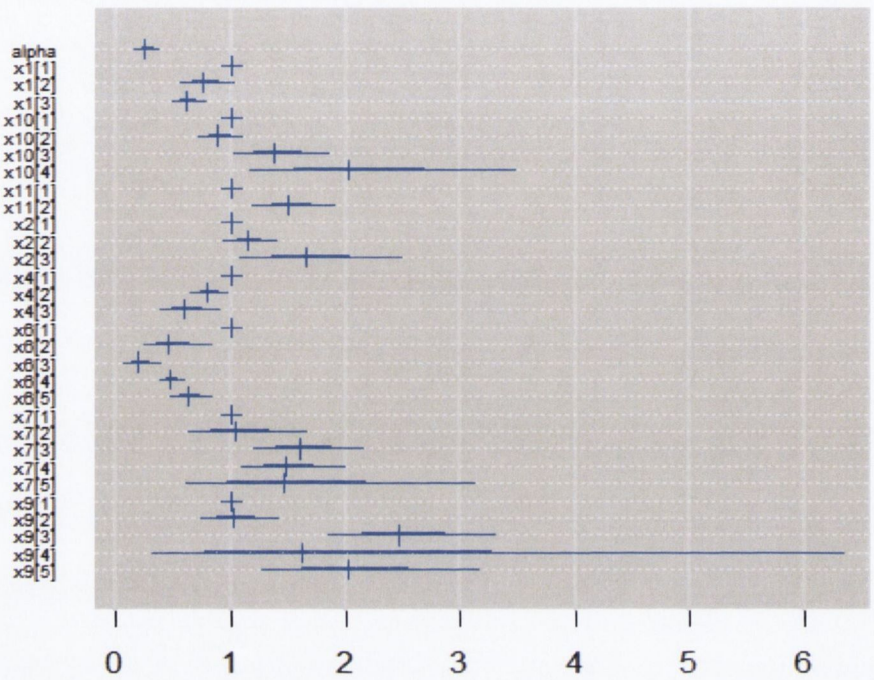

Figure 5.1: Caterpillar plot: Odds of driver-only fatal/serious injuries (2004-2008)

Legend

Label		Label		Label	
alpha	Intercept	x2[2]	Weekend	x7[2]	60km/h
x1[1]	**Day**	x2[3]	public/bank hol	x7[3]	80km/h
x1[2]	Dark with lighting	**x4[1]**	**Dry Surface**	x7[4]	100km/h
x1[3]	Dark	x4[2]	Wet surface	x7[5]	120km/h
x10[1]	**Straight road**	x4[3]	Other surface	**x9[1]**	**Car**
x10[2]	Bend	**x6[1]**	**Object e.g. wall/pole**	x9[2]	Goods vehicle
x10[3]	Hill/gradient	x6[2]	Animal	x9[3]	Motorcycle
x10[4]	Other	x6[3]	Parked vehicle	x9[4]	PSV
x11[1]	**Female**	x6[4]	Ditch	x9[5]	Other
x11[2]	Male	x6[5]	Other		
x2[1]	**Weekday**	**x7[1]**	**50km/h**		

Bold text denotes baseline group; see appendix for variable descriptions

- **Scenario:** collision during daylight hours, on a hill/gradient with a speed limit of 80km/h, on a bank holiday weekday, dry road surface, crashing into a wall/pole
  - Female driver on a motorcycle:
    Predicted probability = 0.67; 95% C.I.(0.30,0.90)
  - Female driving a car:
    Predicted probability = 0.48; 95% C.I.(0.18,0.79)
  - Male driver on a motorcycle:
    Predicted probability = 0.77; 95% C.I.(0.32,0.96)
  - Male driving a car:
    Predicted probability = 0.58; 95% C.I.(0.20,0.87)

- **Scenario:** collision involving a car, during the hours of darkness, on a straight section of road with a speed limit of 50km/h, on a weekday, other road surface (e.g. snow/ice), crashing into a parked vehicle
  - Female driver:
    probability = 0.03; 95% C.I.(0.01,0.11)
  - Male driver:
    Predicted probability = 0.05; 95% C.I.(0.01,0.31)

5.3.2 Evaluation of Collision Injury Model: Single Vehicle Driver Only

Convergence diagnostic tests and plots for the single vehicle logistic 'driver-only' model (2004-2008) are given in the appendix. Examination of these results indicate model convergence.

ROC plots and AUC have been used to validate single vehicle driver only model performance. AUC and ROC plots have been estimated using 2004-2008 data and 2009 data separately. Table 5.10 shows AUC estimations and figures 5.2-5.3 illustrate corresponding ROC plots Visual examination of the plots and AUC figures indicate that the single vehicle collision injury models (2004-2008 and 2009) 'driver only' are low[†] in terms of sensitivity and specificity for the 2004-2008 data and 2009 data.

[†]If AUC=1 the model has perfect performance and if AUC=0.5 the model is not performing any better than random guessing

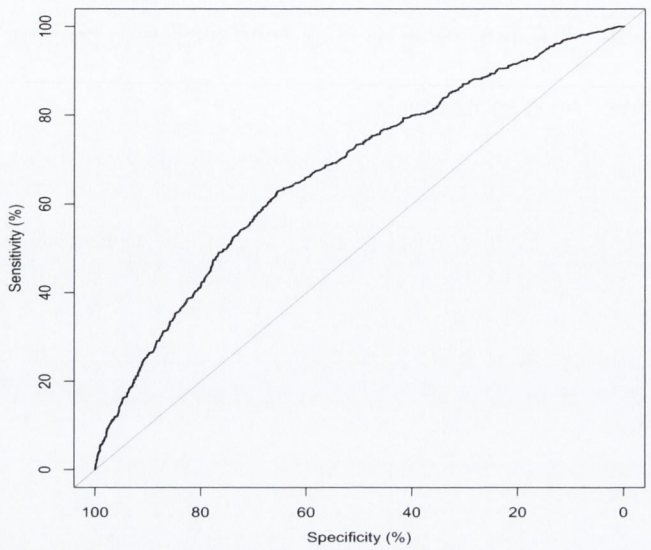

Figure 5.2: ROC Curve: Single vehicle driver-only 2004-2008

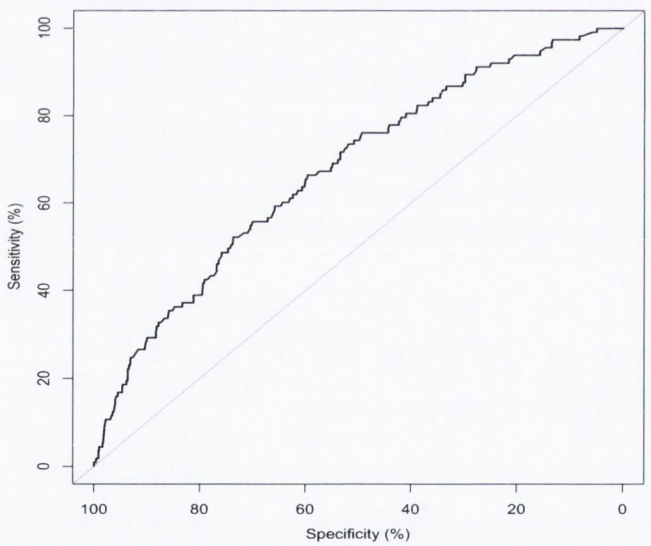

Figure 5.3: ROC Curve: Single vehicle driver-only 2009

Table 5.10: Area Under Curve (single vehicle collisions)

Model	AUC (95% CI)
Driver only(L) 2004-2008	67.3% (64.9%-69.7%)
Driver-only (L) 2009	67.5% (62.3%-72.9%)

(L) denotes Logistic model

5.3.3 Single vehicle 'driver with passengers' collision injuries (2004-2008)

Conditional on a single vehicle 'driver with passengers' collision occurring, results in this section are the odds ratios (O.R.) and corresponding 95% credible interval (95% C.I.) after controlling for the effect of other covariates (see Table 5.11). Statistically significant variables for single vehicle 'driver with passengers' collision injuries include collision type, light, road surface, junction, road geometry, driver age and driver sex. There was insufficient evidence to suggest that speed limit, weekend, time of day, road type and any interactions were significant.

Single vehicle 'driver with passengers' collisions occurring during the hours of darkness[†] were less likely to result in a fatal/serious injury than 'driver with passengers' collisions occurring during the hours of daylight (O.R. 0.53; 95%C.I.(0.43,0.64)) and collisions occurring on a wet road surface as opposed to a dry road surface were also less likely to result in a fatal/serious injury (O.R. 0.79; 95% C.I.(0.66,0.94)). Single vehicle 'driver with passengers' collisions occurring at a junction were less likely to result in a fatal/serious injury than 'driver with passengers' collisions not occurring at a junction (O.R. 0.74, 95% C.I.(0.56,0.98)). Examination of vehicle type indicates that single vehicle 'driver with passenger' motorcycle collisions were more likely to result in a fatal/serious injury than a single vehicle 'driver with passengers' car collision (O.R. 5.41; 95% C.I.(3.22,9.11)). Single vehicle 'driver with passengers' collisions occurring on a hill/gradient were less likely to result in a fatal/serious injury than collisions occurring on a straight section of road (O.R. 0.68, 95% C.I.(0.49,0.93)). Collisions involving male drivers were more likely to result in a fatal/serious injury than collisions involving female drivers (O.R. 1.56; 95%C.I. (1.26,1.93)) and collisions involving drivers under the age of 25yrs were more likely to result in a fatal/serious injury than collisions involving middle aged drivers between 40-64yrs (O.R. 1.36; 95%C.I. (1.05,1.77))

Figure 5.4 shows a caterpillar plot of odds for fatal/serious single vehicle 'driver with passengers' collision injuries.

[†]Hours of darkness is defined as 30 minutes before sunrise and 30 minutes after sunset

Table 5.11: Odds of fatal/serious injuries: 'driver+' single vehicle collisions (2004-2008)

Coefficient	Odds Ratio	(95% C.I.)
Intercept	0.31	(0.22, 0.42)
Light		
Daylight	-	-
Dark (with lighting)	0.75	(0.60,0.94)
Dark	0.53	(0.43,0.64)
Road Surface		
Dry	-	-
Wet	0.79	(0.66,0.94)
Other (e.g. frost/ice)	0.52	(0.34,0.81)
Junction		
No	-	-
Yes	0.74	(0.56,0.98)
Vehicle Type		
Car	-	-
Goods	0.75	(0.53,1.05)
PSV (e.g. bus)	1.05	(0.50,2.20)
Motor Cycle	5.41	(3.22,9.11)
Other	0.89	(0.47,1.69)
Road:		
Straight	-	-
Bend	0.79	(0.66,0.95)
Gradient/Hill Crest	0.68	(0.49,0.93)
Other	1.3	(0.77,2.20)
Collision involving		
Object e.g. wall/pole	-	-
Animal	0.46	(0.27,0.79)
Parked vehicle	0.6	(0.31,1.13)
Ditch	0.51	(0.42,0.61)
Other	0.61	(0.47,0.79)
Age		
40-64 years	-	-
25 years or less	1.36	(1.05,1.77)
26-39 years	0.99	(0.74,1.32)
65+ years	1.34	(0.76,2.35)
Sex		
Female	-	-
Male	1.56	(1.26,1.93)

Driver+ denotes a single vehicle, which contains a driver and at least one passenger.

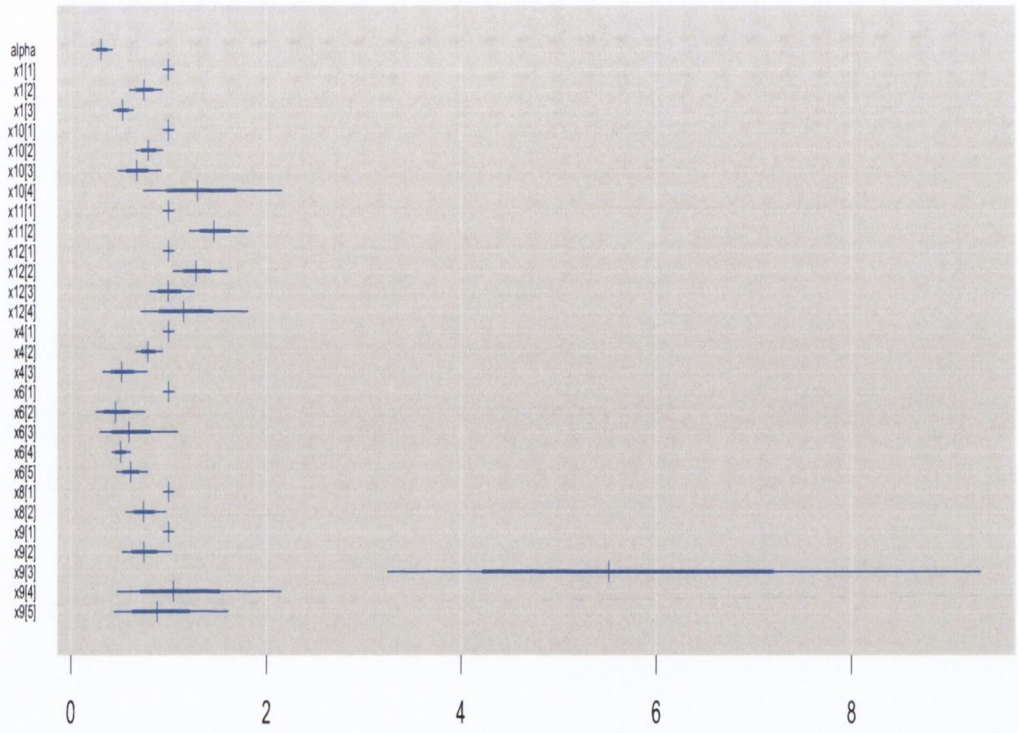

Figure 5.4: Caterpillar plot: Odds of driver+ fatal/serious injuries (2004-2008)

Legend

Label		Label		Label	
alpha	Intercept	**x12[1]**	**40-64yrs**	x6[4]	Ditch
x1[1]	**Day**	x12[2]	<25yrs	x6[5]	Other
x1[2]	Dark with lighting	x12[3]	25-39yrs	**x8[1]**	**Junction: No**
x1[3]	Dark	x12[4]	65+yrs	x8[2]	Junction: Yes
x10[1]	**Straight road**	**x4[1]**	**Dry Surface**	**x9[1]**	**Car**
x10[2]	Bend	x4[2]	Wet surface	x9[2]	Goods vehicle
x10[3]	Hill/gradient	x4[3]	Other surface	x9[3]	Motorcycle
x10[4]	Other	**x6[1]**	**Object e.g. wall/pole**	x9[4]	PSV
x11[1]	**Female**	x6[2]	Animal	x9[5]	Other
x11[2]	Male	x6[3]	Parked vehicle		

Bold text denotes baseline groups; see appendix for variable descriptions

Predicted Probability: Fatal/Serious Single Vehicle Driver With Passengers Collision Injuries (2004-2008)

Predicted probabilities* of fatal/serious injuries as a result of a single vehicle driver with passengers collision occurring in a number of different scenarios† are given for both young and middle-aged drivers‡:

- **Scenario:** collision involving a car, during daylight hours, on a straight section of road with a dry road surface, not at a junction, crashing into a wall/pole§
  - Middle aged female driver: Predicted probability = 0.24; 95%CI (0.18,0.30)
  - Young female driver: Predicted probability = 0.28; 95%CI (0.19,0.40)
  - Middle aged male driver: Predicted probability = 0.31 95%CI (0.21,0.44)
  - Young male driver: Predicted probability = 0.37; 95%CI (0.22,0.55)

- **Scenario:** collision involving a motorcycle, during daylight hours, straight section of road, not at a junction, on a dry road surface, crashing into a wall/pole
  - Middle aged female driver: Predicted probability = 0.49; 95%CI(0.39,0.49)
  - Young female driver: Predicted probability = 0.52; 95%CI(0.40,0.51)
  - Middle aged male driver: Predicted probability = 0.71; 95%CI(0.47,0.88)
  - Young male driver: Predicted probability = 0.76; 95%CI(0.48,0.92)

- **Scenario:** collision involving a car, during the hours of darkness, at a junction on a hill-crest/gradient, other road surface (e.g. snow/ice), crashing into an animal
  - Middle aged female driver: Predicted probability = 0.03; 95%CI(0.01,0.18)
  - Young female driver: Predicted probability = 0.04; 95%CI(0.01,0.27)
  - Middle aged male driver: Predicted probability = 0.05; 95%CI(0.01,0.29)
  - Young male driver: Predicted probability = 0.06; 95%CI(0.01,0.40)

*Predicted probability = (odds/(1+odds))

†Examination of the caterpillar interval plot (5.4) shows that the scenarios given in the text give a range of conditions that produce high predicted probabilities and low predicted probabilities for fatal/serious single vehicle driver only collision injuries

‡Middle aged driver denotes a driver aged between 40-64yrs (inclusive) and young driver denotes a driver aged under 25yrs

§This single vehicle driver with passenger scenario for a female driver aged 40-64yrs denotes the model intercept

5.3.4 Evaluation of Collision Injury Model: Single Vehicle Driver With Passengers

Convergence diagnostic tests and plots for the single vehicle binomial ('driver with passengers') model (2004-2008) are given in the appendix. Examination of these results indicate model convergence.

ROC plots and AUC have been used to validate single vehicle 'driver with passengers' model performance. AUC and ROC plots have been estimated using 2004-2008 data and 2009 data separately. Table 5.13 shows AUC estimations and figures 5.5-5.6 illustrate corresponding ROC plots Visual examination of the plots and AUC figures indicate that the single vehicle collision injury models (2004-2008 and 2009) 'driver with passengers' are low[†] in terms of sensitivity and specificity for the 2004-2008 data and 2009 data.

Table 5.13: Area Under Curve (single vehicle collisions)

Model	AUC (95% CI)
Driver-with passenger(B) 2004-2008	65.5% (62.5%-68.5%)
Driver-with passenger (B) 2009	65.8% (59.5%-72.0%)

(B) denotes Binomial model

[†]If AUC=1 the model has perfect performance and if AUC=0.5 the model is not performing any better than random guessing

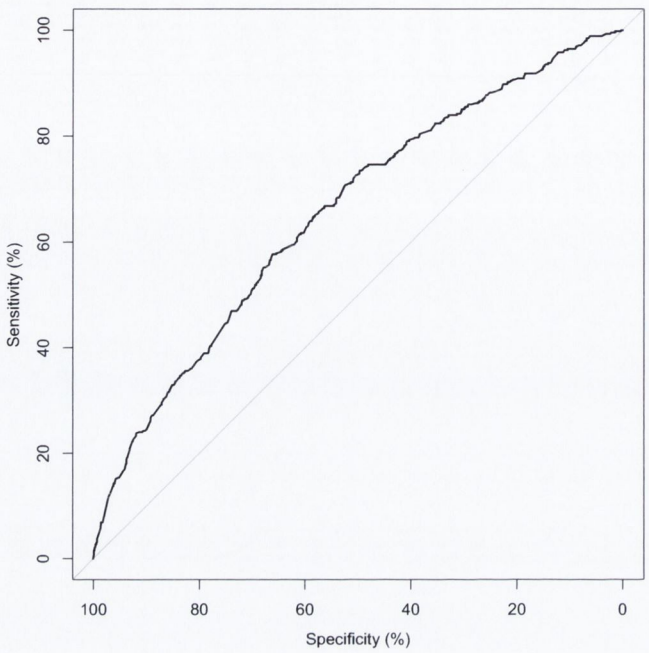

Figure 5.5: ROC Curve: Single vehicle driver with passengers 2004-2008

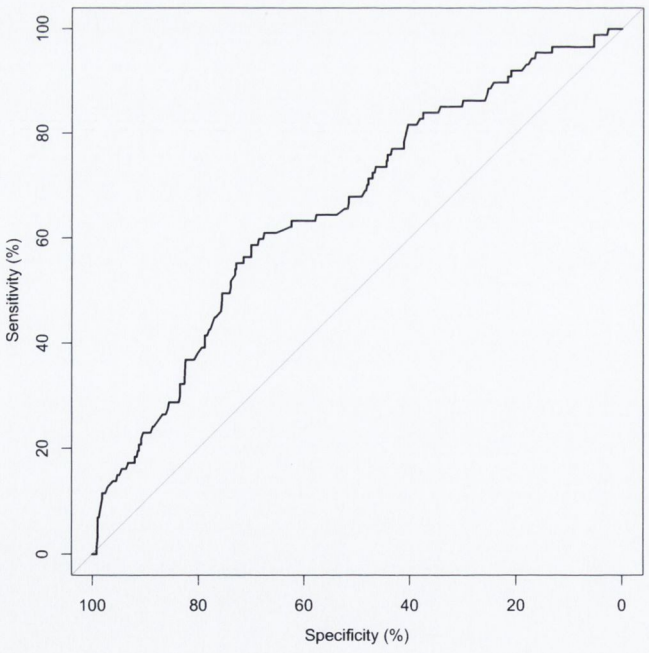

Figure 5.6: ROC Curve: Single vehicle driver with passengers 2009

5.4 Results: Multi-Vehicle Collision Injuries (2004-2008)

Conditional on a multi-vehicle collision occurring, results in this section are the odds ratios (O.R.) and corresponding 95% credible interval (95% C.I.) after controlling for the effect of other covariates (see Table 5.14). Statistically significant variables for multi-vehicle collision injuries include collision type, light, road surface, junction, road geometry, speed limit, weekend and road type. There was insufficient evidence to suggest that number of vehicles involved, time of day and any interactions were significant.

Model results indicate that multi-vehicle collisions occurring during the hours of darkness were less likely to contain a fatal/serious injury than collisions occurring during daylight (O.R. 0.71; 95% C.I.(0.63,0.80)) whereas multi-vehicle collisions occurring at the weekend (O.R. 1.24; 95%C.I.(1.12,1.36)) or on a public/bank holiday weekend (O.R. 1.44; 95%C.I.(1.12,1.84)) were more likely to result in a fatal/serious injury. Fatal/serious injuries were more likely to occur as speed limit increased. Multi-vehicle collisions were more likely to result in a fatal/serious injury on national primary road than on national secondary roads (O.R. 1.66; 95%C.I.(1.42,1.93)). Similarly multi-vehicle collisions were less likely to result in a fatal/serious injury on wet surface roads than dry surface roads (O.R. 0.81; 95%C.I.(0.74,0.89)). Collisions occurring at a junction (O.R. 0.63; 95%C.I.(0.56,0.71)) or rear-end (O.R. 0.19; 95%C.I.(0.16,0.21)) and angle (O.R. 0.44; 95%C.I.(0.39,0.49)) collisions as opposed to head-on collisions were also less likely to result in a fatal/serious injury.

Table 5.14: Odds of fatal/serious injuries: multi-vehicle collisions (2004-2008)

Coefficient	Odds Ratio	(95% C.I.)
Intercept	0.10	(0.08,0.12)
Light		
Daylight	-	-
Dark (with lighting)	0.76	(0.64,0.9)
Dark	0.71	(0.63,0.8)
Day		
Week day	-	-
Weekend	1.24	(1.12,1.36)
Public/Bank holiday weekend	1.44	(1.12,1.84)
Road Type		
National Secondary Rd	-	-
National Primary Rd	1.66	(1.42,1.93)
Regional/local Rd	0.91	(0.78,1.06)
Road Surface		

Continued on next page

Table 5.14 – Odds of fatal/serious injuries: multi-vehicle collisions (2004-2009) contd.

Coefficient	Median	95% C.I.
Dry	-	-
Wet	0.81	(0.74,0.89)
Other (e.g. frost/ice)	0.73	(0.56,0.96)
Speed Limit		
50km/h	-	-
60km/h	1.61	(1.29,2)
80km/h	2.03	(1.76,2.35)
100km/h	2.67	(2.29,3.11)
120km/h	2.92	(1.81,4.72)
Junction		
No	-	-
Yes	0.63	(0.56,0.71)
Collision Type		
Head-on	-	-
Angle	0.44	(0.39,0.49)
Rear-end	0.19	(0.16,0.21)
Road:		
Straight	-	-
Bend	1.03	(0.92,1.16)
Gradient/Hill Crest	1.29	(1.13,1.47)
Other	1.55	(1.18,2.04)

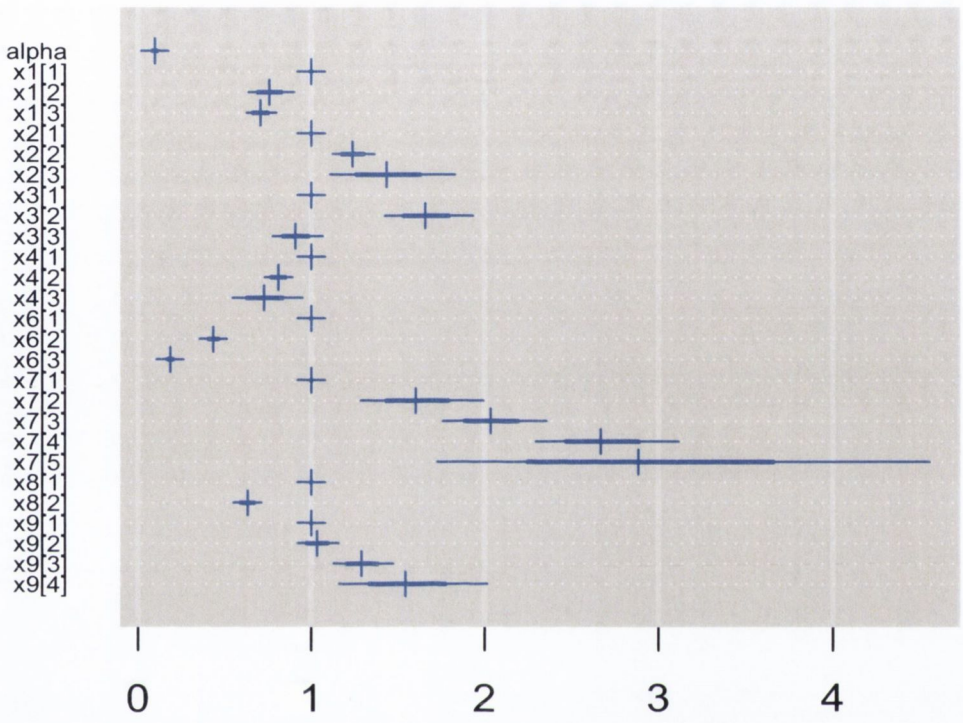

Figure 5.7: Caterpillar plot: Odds of multi-vehicle fatal/serious injuries 2004-2008

Legend

Label		Label		Label	
alpha	Intercept	x3[3]	Regional/local road	x7[3]	80km/h
x1[1]	**Day**	**x4[1]**	**Dry surface**	x7[4]	100km/h
x1[2]	Dark with lighting	x4[2]	Wet Surface	x7[5]	120km/h
x1[3]	Dark	x4[3]	Other surface	**x8[1]**	**Junction: No**
x2[1]	**Week day**	**x6[1]**	**Head-on collision**	x8[2]	Junction: Yes
x2[2]	Weekend	x6[2]	Angle collision	**x9[1]**	**Straight road**
x2[3]	Public/Bank holiday weekend	x6[3]	Rear-end collision	x9[2]	Bend
x3[1]	**Secondary road**	**x7[1]**	**50km/h**	x9[3]	Hill/gradient
x3[2]	Primary road	x7[2]	60km/h	x9[4]	Other

Bold text denotes baseline group; see appendix for variable descriptions

Predicted Probability of Fatal/Serious Multi-Vehicle Collision Injuries (2004-2008)

Predicted probabilities* of fatal/serious injuries as a result of a multi-vehicle collisions occurring in a number of different scenarios† are given as follows:

- **Scenario:** head-on collision occurring during daylight hours on a week day, on a straight section of road with a dry road surface, not a junction ‡
  - National secondary road with a 50km/h speed limit
    Predicted probability = 0.09; 95%CI (0.07,0.10)
  - National secondary road with a 80km/h speed limit§
    Predicted probability = 0.16; 95%CI (0.11,0.22)
  - National primary road with a 50km/h speed limit
    Predicted probability = 0.14; 95%CI (0.10,0.15)
  - National primary road with a 100km/h speed limit¶
    Predicted probability = 0.10; 95%CI (0.06,0.15)

- **Scenario:** collision occurring on a national primary road with a speed limit of 100km/h, during daylight hours on a bank holiday weekend, on a hill/gradient, not at a junction, on a dry road surface
  - Head-on collision:
    Predicted probability = 0.43; 95%CI(0.24,0.66)
  - Angle collision:
    Predicted probability = 0.25; 95%CI(0.11,0.28)
  - Rear-end collision:
    Predicted probability = 0.12; 95%CI(0.05,0.29)

---

*Predicted probability = (odds/(1+odds))

†Examination of the caterpillar interval plot (5.7) shows that the scenarios given in the text give a range of conditions that produce high predicted probabilities and low predicted probabilities for fatal/serious multi-vehicle collision injuries

‡This multi-vehicle scenario occurring on a national secondary road with a speed limit of 50km/h denotes the model intercept

§National secondary roads have a default speed limit of 80km/h

¶National primary roads with a speed limit of 120km/h are motorways, In the scenario outlined in the above text, the baseline collision type is 'head-on' collision, directional traffic flow on motorways are always separated by a median strip/barrier, thus predicted probabilities under this scenario will not be given for national primary roads with a speed limit of 120km/h

- **Scenario:** collision occurring on a national secondary road with a speed limit of 50km/h, during hour of darkness on a week day, on a straight section of road at a junction with a snow/ice road surface
  - Rear-end collision: predicted probability = 0.01; 95%CI(0.00,0.02)
  - Angle collision: predicted probability = 0.01; 95%CI(0.01,0.03)
  - Head-on collision: predicted probability = 0.03; 95%CI(0.01,0.06)

5.4.1 Evaluation of Multi-Vehicle Collision Injury Model

Convergence diagnostic tests and plots for the multi-vehicle binomial model (2004-2008) are given in the appendix. Examination of these results indicate model convergence.

ROC plots (see Figures 5.8-5.9) and AUC (see Table 5.16) have been estimated for multi-vehicle collision injuries using collision data from (2004-2008) and (2009) separately. Visual examination of the plots and AUC figures indicate that the models are reasonably accurate in terms of sensitivity and specificity foe the 2004-2008 data and have surprisingly good accuracy for the 2009 data.

Table 5.16: Area Under Curve (multi-vehicle collisions)

Model	AUC (95% CI)
Multi-vehicle collision injuries 2004-2008	73.7% (72.4%-75.1%)
Multi-vehicle collision injuries 2009	80.1% (77.0%-83.2%)

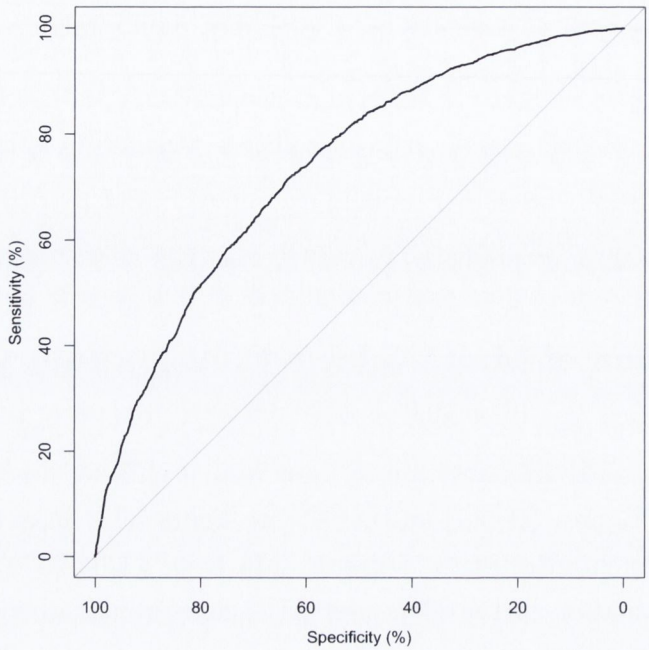

Figure 5.8: ROC Curve: Multi-vehicle collision injuries 2004-2008

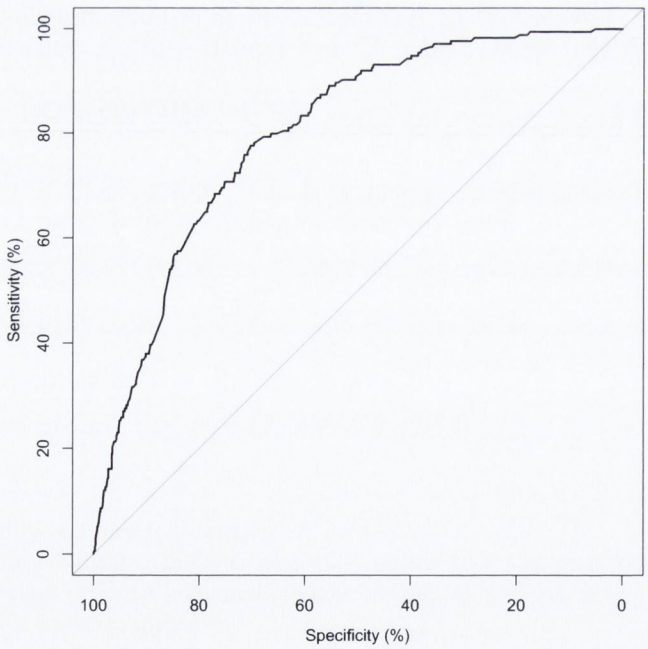

Figure 5.9: ROC Curve: Multi-vehicle collision injuries 2009

5.5 Summary

A Full Bayesian framework was used to estimate logistic regression models for fatal/serious 'driver only' single vehicle collision injuries. Two binomial regression models were also estimated for fatally/seriously injured persons as a proportion of the total number of persons involved in 'driver with passengers' single vehicle collisions and persons involved in multi-vehicle collisions. Statistically significant explanatory variables for single vehicle 'driver only' collisions included driver sex, light, public/bank holiday weekend, speed limit, road surface, road geometry, vehicle type and collision type. In comparison, statistically significant explanatory variables for single vehicle 'driver with passengers' collisions included driver age, driver sex, light, road surface, road geometry, vehicle type, junction and collision type. Unfortunately, due to data limitations driver age and driver sex was not available for the multi-vehicle collision injury model, however statistically significant explanatory variables include light, weekend, road type, road surface, speed limit, road geometry, junction and collision type.

Model results indicated that single vehicle 'driver only' (O.R. 0.61; 95%C.I.(0.49,0.77)),'driver with passengers'(O.R. 0.53; 95%C.I.(0.43,0.64)) and multi-vehicle (O.R. 0.71; 95%C.I.(0.63,0.80)) collisions occurring during the hours of darkness were less likely to contain a fatal/serious injury than collisions occurring during daylight. Single vehicle 'driver only' (O.R. 0.80; 95%C.I.(0.65,0.98)),'driver with passengers'(O.R. 0.79; 95%C.I.(0.66,0.94))) and multi-vehicle (O.R. 0.81; 95%C.I.(0.74,0.89)) collisions occurring on a wet road surface were also less likely to result in a fatal/serious injury. Single vehicle 'driver only' (O.R. 1.37; 95%C.I.(1.02,1.85)) and multi-vehicle (O.R. 1.29; 95%C.I.(1.13,1.47)) collisions occurring on a hill/gradient were more likely to contain a fatal/serious injury than collisions occurring on a straight section of road, however, in contrast, single vehicle 'driver with passengers' (O.R. 0.68; 95%C.I.(0.49,0.93)) collisions occurring on a hill/gradient were less likely to contain a fatal/serious injury. Multi-vehicle (O.R. 0.63; 95%C.I.(0.56,0.71)) and single vehicle 'driver with passengers' (O.R. 0.74; 95%C.I.(0.56,0.98)) collisions occurring at a junction were less likely to contain a fatal/serious injury and collisions occurring on roads with a speed limit greater than 50km/h were more likely to contain a fatal/serious injury. Male drivers involved in a single vehicle 'driver only' (O.R. 1.49; 95%C.I.(1.18,1.89)) and 'driver with passengers'(O.R. 1.56; 95%C.I.(1.26,1.93)) collision were more likely to sustain a fatal/serious injury than female drivers. Multi-vehicle (O.R. 1.44; 95%C.I.(1.12,1.84))and single vehicle 'driver-only' (O.R. 1.65; 95%C.I.(1.10,2.49)) collisions occurring on a public/bank holiday weekend were more likely to contain a fatal/serious injury than collisions occurring on a week day.

Conditional on the occurrence of a single vehicle 'driver only' collision the predicted

probability of a fatal/serious injury as a result of a single vehicle collision involving a car, during daylight hours, on a straight section of road with a speed limit of 50km/h, on a weekday, dry road surface, crashing into a wall/pole is lower for female drivers (predicted probability = 0.20; 95% C.I.(0.14,0.27)) than for male drivers (predicted probability = 0.27; 95% C.I.(0.16,0.41)). Under the same conditions, the predicted probability of a fatal/serious injury for both male and female drivers increases when the speed limit of the road increases to 100km/h, however female drivers (predicted probability = 0.27; 95% C.I.(0.15,0.43)) under these circumstances still have a lower predicted probability than male drivers (predicted probability = 0.35; 95% C.I.(0.18,0.59)).

Conditional on the occurrence of a single vehicle 'driver with passengers' collision the predicted probability of a fatal/serious injury as a result of a single vehicle collision involving a car, during daylight hours, on a straight section of road with a dry road surface, not at a junction, crashing into a wall/pole was higher for young male drivers under the age of 25 years (predicted probability = 0.37; 95%CI (0.22,0.55))than middle aged driver aged 40-64 years (predicted probability = 0.31 95%CI (0.21,0.44)). Both young female (Predicted probability = 0.28; 95%CI (0.19,0.40)) and middle-aged female (Predicted probability = 0.24; 95%CI (0.18,0.30)) drivers had a lower predicted probability of a fatal/serious injury than their male counter parts.

Unfortunately, due to poor quality data, information regarding age and sex were unavailable in the multi-vehicle collision data set. However, despite data limitations, model results showed that predicted probabilities of a fatal/serious injuries occurring as a result of a multi-vehicle collision differ depending on the type of multi-vehicle collision, as for example a multi-vehicle collision occurring on a national primary road with a speed limit of 100km/h, during daylight hours on a bank holiday weekend, on a hill/gradient, not at a junction, on a dry road surface has a predicted probability of 0.43 (95%CI(0.24,0.66)) for a head-on collision, 0.25 (95%CI(0.11,0.28)) for an angle collision and 0.12 (95%CI(0.05,0.29)) for a rear-end collision

In conclusion, this chapter has provided results from logistic regression models for single vehicle 'driver only' and binomial regression models for single vehicle 'driver with passengers' and multi-vehicle collision injuries to give an overall view from a national perspective on the different characteristics associated with fatal/serious injuries which result from single vehicle and multi-vehicle collisions in Ireland (2004-2008).

Chapter 6

Discussion & Conclusion

The aim of this study was to develop and deploy the required efficient statistical methodology for identifying road traffic collision hot spots & corridors along the road network in Ireland and to assess the human, environmental and infrastructural factors associated with fatal/serious injuries sustained as a result of single vehicle and multi-vehicle road traffic collisions. To date scan statistics have not been used to detect road collision hot spots/corridors in Ireland. This study is the first study to implement scan statistics to the whole national road network and devise a systematic approach to identify multiple collision hot spots/corridors along each individual road. The creation of geographical maps illustrates all identified collision hot spots/corridors for each national road in Ireland. In addition to the applicability of scan statistics to Irish road traffic collision data, and the development of a systematic approach for extracting multiple hot spots/corridors on individual roads, previously unreported findings relating to the underlying distribution of road traffic collisions along the road network have emerged from this study. If the underlying distribution of collisions on a particular road (or section of road) is uniform then scan statistics will not identify a collision hot spot/corridor even though these collisions may actually be a collision hot spot/corridor. This finding highlights the importance of examining the underlying distribution of collisions before applying scan statistics. As collisions occurring at road collision hot spots/corridors only represent a fraction of collisions, Bayesian global models were used to determine explanatory factors associated with single vehicle and multi-vehicle collisions which occurred on the Irish road network thus providing stakeholders (Road Safety Authority, National Roads Authority and An Garda Síochána) a meaningful insight to all road traffic collisions (in addition to the specific focus on road traffic collisions occurring at collision hot spots/corridors).

This chapter provides a discussion of the applicability of scan statistics applied to road traffic collisions in the Republic of Ireland. An examination of results obtained from the scan statistics analysis are given in sections 6.1 - 6.2 and findings from the global

collision models for single vehicle collisions and multi-vehicle collisions are discussed in section 6.3. Section 6.4 outlines the advantages of examining both global and focused analysis of road traffic collisions. Limitations and suggestions for future research will also be discussed in sections 6.5 - 6.6 and finally concluding remarks are outlined in section 6.7.

6.1 Temporal and Spatio-temporal Scan Statistics

Identification of temporal clusters of road traffic collisions in Ireland were obtained through the application of fixed window temporal scan statistics (Naus' fixed window scan statistic) to all fatal/serious road traffic collisions recorded in the Republic of Ireland from 2005-2009 and (Bernoulli model) to all road traffic collisions occurring in cities of Dublin, Cork, Limerick, Galway and Waterford from 2005-2009. Unfortunately the inability to identify the geographical location of these significant clusters provides a major disadvantage of both aforementioned approaches. Application of a space-time permutation partially resolves the issue of location as this approach enables the identification of collision clusters on both a temporal and spatial scale, however this approach does not restrict cluster identification to an individual road hence such analyses are of limited value for policy purposes, as significant clusters identified (via the space-time permutation model) span large geographic areas. Discovery of clusters along a road network is of particular interest as collisions occurring on a national primary road (e.g. Stilorgan Rd, Dublin) may have a different pattern than collisions occurring on a regional road (Merrion Rd, Dublin) because national primary roads and regional roads are structurally different e.g. national primary roads are designed to carry large volumes of traffic.

6.2 Variable Window Scan Statistic

Building on the work of Naus [219], Nagarwalla devised a variable window scan statistic to examine birth defects observed in a hospital in Birmingham. The method involved the application of a moving window with variable width and evidence of clustering was measured in terms of a likelihood ratio rather than the absolute number of points in the window [221]. Adopting the variable window scan statistic to road traffic collisions required the adaptation of Nagarwalla's scan statistic to distance along a (linear) road as distinct to distance in (linear) time.

Application of the variable window scan statistic to road traffic collisions occurring on national primary roads provides an informative monitoring tool to identify road collision hot spots and corridors, thus enabling the examination of collision characteristics at these

locations. International literature applying scan statistics to a network (e.g. road, pipes etc.) all extract the most likely cluster on a particular network[205],however there is no examination of multiple clusters along a network.

This study extracts the most likely cluster and secondary clusters on the same network e.g. three collision hot spots/corridors (clusters) were identified on the N7 national primary road (Dublin-Limerick route).

6.2.1 Multiple cluster extraction

Identifying the most significant cluster along individual roads poses no issues, however the extraction of multiple clusters requires the issues of roll-over and overlapping clusters to be addressed. Examining all plausible clusters when clusters are not ranked by maximum values i.e. clusters are arranged according to their location on the road (i.e. starting at the beginning and finishing at the end of the road) resulted in clusters with large spanning distances being identified e.g. N2 national primary road (Dublin-Derry route) had a cluster containing 182 collisions over 72.6km. Identification of clusters with large spanning distances are of dubious practical value, thus extracting significant clusters by restricting spanning distance to 5km (i.e corridors) and 500m (i.e. hot spots) was examined. Unfortunately extraction of significant clusters via restricting spanning distance resulted in overlapping/roll-over clusters. An example of roll over clusters was demonstrated via examination of significant clusters identified on the N2 national primary road. There were 6 hot spots identified by restricting cluster spanning distances to 500m. Two of these hot spots were roll-over clusters of approximately 500m in length each, thus resulting in one amalgamated collision corridor (approx. 1km in length) located on Finglas Rd., Dublin. Similarly, two of the remaining hot spots identified on Phibsborough Rd. were 'roll-over' hotspots which resulted in one amalgamated collision corridor (approx. 1km in length). In order to overcome these issues (of overlap/roll-overs) and prevent bias in the selection of clusters a systematic approach was devised in this study. The spanning distance of the clusters was not restricted, extracting collision corridors and hot spots was based on maximum values i.e. the most likely cluster 'M' was identified (by maximum value) then remaining clusters that included any part/overlapped into 'M' were not considered in the identification process. The second most likely cluster was then identified by maximum value and the above process repeated until all clusters identified. This approach identifies non-overlapping/roll over clusters and provides clusters with reasonable spanning distances (in the majority of cases, see table 4.6, p.66).

6.2.2 Semantic Segmentation and Multiple Collision Hot Spots/Co Extraction

Semantic segmentation on a linear network was introduced by Janeja & Atluri [205]. This concept of semantic segmentation was adopted in the identification of collision hot spots/corridors occurring on Irish national secondary roads, because these road often had continuity broken by other roads, thus providing natural semantic segments.

The unique aspect of this study (on road traffic collisions on the Irish road network) was using semantic segmentation and scan statistics to identify multiple hot spots/corridors on national secondary roads and also provide corresponding collision characteristics at these identified locations. Further exploration of semantic segmentation was applied to the N81 national secondary road (Dublin City Centre - Tullow, Co.Carlow route). Traversing this route (personally by car) and manually recording of speed limits enabled semantic segmentation of this road based on speed limit zones. Comparison of results obtained from running the scan on the whole N81 road versus the results obtained from running the scan on individual speed limit zones showed that clusters identified in speed zones 1 & 2 were both sub-clusters contained in the most significant cluster that was identified by running the scan statistic on the whole N81 road. However, the cluster identified in speed zone 3 was not identified as significant when the whole N81 road was taken into consideration.

Following the analysis performed on national primary and secondary roads, the scan statistic was applied to two regional roads (see p.95) - the R423 (Mountrath, Co.Laois) and R402 (Enfield, Co.Meath). Numbers of collision recorded on these road were substantially lower than the majority of national primary/secondary roads. Eighty three collisions were recorded on the R402. This particular road was chosen for this study as it contained a known speed collision prone zone (as identified by An Garda Síochána via speed collision surveys). Running the scan statistic on the whole R402 route identified a significant collisions prone zone (which was the same as the zone identified by the Gardaí). Only seven collisions were recorded on the R423, and running the scan statistic on the whole R423 road identified a significant cluster with five collisions which resulted in two fatal injuries (This cluster was not identified as a speed collision prone zone by the Gardaí). Applying semantic segmentation to the R423 (using local roads as a boundary) lead to the scan being run on a section of road beginning at Ballyfin Co.Laois and ending at the R423 intersection with the N80. This section contained six recorded collisions, however no significant cluster was identified (even when the minimum scanning window was changed from the default number of 5 collisions (as suggested by Nagarwalla [221]) to a minimum window of 4 or 3 collisions).

In reality the road network consists of intersecting roads thus in order to accommodate this characteristic Shi & Janeja [244] suggested applying the scan statistic to combinations of roads which incorporated the intersection. This study examined the intersection which was incorporated in the most likely cluster on regional road R402 (see p.99-101). Findings indicated that this approach was reasonable for identification of collision hot spots/corridors occurring at an intersection, however during the process of examining different combinations of segments to identify collision hot spots/corridors an interesting finding regarding the underlying distribution of collisions emerged.

6.2.3 Uniformity of Road Traffic Collisions

The underlying assumption of Nagarwalla's variable scan statistic is that road traffic collisions are uniformly distributed along the road network and if collisions deviate from the uniform distribution, this constitutes a cluster. Findings in this study indicate that there are situations where a group of collisions occurring on a particular road (or section of road) are uniformly distributed but this uniform grouping of collisions itself is actually a cluster. An example of this was seen for the R423 regional road and the R402 regional road (see section 4.8, p.95). The reason as to why no significant cluster was identified by examining the R402 (bounded by R441) / R402 (bounded by local road) presents an interesting finding is because this section of road contains 17 collisions, all of which have been identified as part of the most significant cluster when the scan was run on the whole of the R402 road (and also when the scan was run on the R402/R441 - R402/R403 section). Collisions recorded in the R402 (bounded by R441) / R402 (bounded by local road) section are uniformly distributed, thus running the scan on these collisions resulted in the null hypothesis not being rejected, even though looking at the road as a whole these collisions form a significant cluster. These findings indicate that any future research would require graphical mapping of collisions on the road and a checking the assumption of uniformity before proceeding (e.g. Chi-square).

6.2.4 Scan Statistics & Garda Speed Prone Zones

An Garda Síochána have designated speed collision prone zones on the Irish road network by performing speed collision surveys and analysing road traffic collision data. Through the application of scan statistics this study has identified road collision hot spots/corridors on the Irish national road network. Comparison of locations identified in this study and speed collision prone zones identified by the Gardaí indicates some of the collision hot spots/corridors identified (via scan statistics) are located within a designated speed collision prone zone, as for example one significant collision corridor in Dublin City of

6.7km in length was identified via scan statistics on the N2 national primary road. This collision corridor (beginning on Finglas Rd. and ending on Berkley Rd.) contained 75 collisions where 3 serious injuries and 2 fatalities were sustained. The speed collision prone zones were identified by the Gardaí in Dublin City were located on Finglas Rd. (approx. 2.7km in length) and Phibsborough Rd. (approx. 1.1km in length) however the Gardaí do not have a collision prone zone designated for Berkley Rd, thus indicating that scan statistics are more specific as it identifies one significant collision corridor as opposed to two individual speed collision prone zones.

None of the road traffic collision hot spots/corridors identified on the N52 via scan statistics correspond to the speed collision prone zones identified by the Gardaí, however scan statistics have selected locations in which fatal/serious collisions have occurred e.g. the collision corridor located in Co.Offaly (via scan statistics) contains 9 collisions where one serious injury and one fatality were sustained (see cluster 1, p.81). There is no designated Garda speed collision prone zone located on the R423 regional road, however through the application of scan statistics a collision corridor of 1.3km in length has been identified. This collision corridor contains 5 collisions where four serious injuries and two fatalities were sustained.

Scan statistics identified a number of collision hot spots/corridors comparable to speed collision prone zones identified by the Gardaí, however findings have indicated that scan statistics are more sensitive in identification, as for example the speed collision prone zone identified (by the Gardaí) on the N81 national secondary road (spanning approx. 4km in length) in Blessington, Co.Wicklow incorporates the road collision hot spot (spanning 288m in length) (identified via scan statistics). Similarly the collision corridor (identified via scan statistics) which is approximately 1.9km in length and contains 23 collisions (three serious injuries and zero fatalities) is incorporated by the 5km speed collision prone zone that was designated by the Gardaí.

6.3 Global Models

The study of single vehicle road traffic collisions occurring in Ireland, has shown that the factors influencing fatal/serious collisions cover a diverse number of areas - environmental, road infrastructure and geometry, human characteristics and vehicle type. Findings from 'driver-only' and 'driver with passengers' models give meaningful insights into single vehicle collisions thus giving an improved comprehension of the circumstances surrounding these collisions.

Approximately 18% (714/3931) of driver-only single vehicle collisions resulted in a fatal/serious injury. Statistically significant variables for single vehicle 'driver only' col-

lisions include collision type, light, public/bank holiday weekend, road surface, road geometry, speed limit and driver sex. There was insufficient evidence to suggest that driver age, time of day, junction and road type and any interactions were significant.

Fatal/serious injuries were less likely to result from single vehicle 'driver only' collisions occurring during the hours of darkness as opposed to daylight hours and less likely on a wet road surface as opposed to a dry road surface. Single vehicle 'driver only' collisions occurring on a public/bank holiday weekend were more likely to result in a fatal/serious injury than 'driver only' collisions occurring on a week day and single vehicle 'driver only' motorcycle collisions were more likely to result in a fatal/serious injury than a single vehicle 'driver only' car collision, which indicates that cars are more protective in a collision than motorcycles. Driver only collisions occurring on roads with a speed limit of 80km/h or 100km/h were more likely to contain a fatal/serious injury than collisions occurring on roads with a speed limit of 50km/h, which implies that collisions on roads with higher speed limits are more likely to result in a fatal/serious injury. Single vehicle 'driver only' collisions occurring on a hill/gradient were more likely to result in a fatal/serious injury than collisions occurring on a straight section of road. Male drivers involved in a single vehicle 'driver only' collision were more likely to sustain a fatal/serious injury than female drivers.

Conditional on the occurrence of a single vehicle 'driver only' collision the predicted probability of a fatal/serious injury as a result of a single vehicle collision involving a car, during daylight hours, on a straight section of road with a speed limit of 50km/h, on a weekday, dry road surface, crashing into a wall/pole is lower for female drivers (predicted probability = 0.20; 95% C.I.(0.14,0.27)) than for male drivers (predicted probability = 0.27; 95% C.I.(0.16,0.41)). Under the same conditions, the predicted probability of a fatal/serious injury for both male and female drivers increases when the speed limit of the road increases to 100km/h, however female drivers (predicted probability = 0.27; 95% C.I.(0.15,0.43)) under these circumstances still have a lower predicted probability than male drivers (predicted probability = 0.35; 95% C.I.(0.18,0.59).

Approximately, 31% (536/1732) of single vehicle collisions involving a driver and passengers in the vehicle result in at least one fatal/serious injury. Statistically significant variables for single vehicle 'driver with passengers' collision injuries include collision type, light, road surface, junction, road geometry, driver age and driver sex. There was insufficient evidence to suggest that speed limit, weekend, time of day, road type and any interactions were significant.

Similar to the findings from the single vehicle 'driver only' model, 'driver with passengers' collisions occurring during the hours of darkness were less likely to result in a fatal/serious injury than during the hours of daylight hours and collisions occurring on

a wet road surface as opposed to a dry road surface were also less likely to result in a fatal/serious injury. Single vehicle 'driver with passengers' collisions occurring at a junction were less likely to result in a fatal/serious injury than 'driver with passengers' collisions not occurring at a junction, which may be due to the slow speed a vehicle would be travelling when the vehicle is at a junction. Examination of vehicle type indicates that single vehicle 'driver with passenger' motorcycle collisions were more likely to result in a fatal/serious injury than a single vehicle 'driver with passengers' car collision, which implies that certain vehicles are more protective in a collision. Single vehicle 'driver with passengers' collisions occurring on a hill/gradient were less likely to result in a fatal/serious injury than collisions occurring on a straight section of road, this finding is in contrast to the single vehicle 'driver only' result, and a number of plausible reasons may be suggested e.g. drivers of vehicles containing passengers may drive more cautiously, or may travel at slower speeds. Collisions involving male drivers were more likely to result in a fatal/serious injury than collisions involving female drivers and collisions involving drivers under the age of 25yrs were more likely to result in a fatal/serious injury than collisions involving middle aged drivers between 40-64yrs

Conditional on the occurrence of a single vehicle 'driver with passengers' collision the predicted probability of a fatal/serious injury as a result of a single vehicle collision involving a car, during daylight hours, on a straight section of road with a dry road surface, not at a junction, crashing into a wall/pole was higher for young male drivers under the age of 25 years (predicted probability = 0.37; 95%CI (0.22,0.55))than middle aged driver aged 40-64 years (predicted probability = 0.31 95%CI (0.21,0.44)). Both young female (Predicted pro = 0.28; 95%CI (0.19,0.40)) and middle-aged female (Predicted probability = 0.24; 95%CI (0.18,0.30)) drivers had a lower predicted probability of a fatal/serious injury than their male counter parts.

Approximately, 13% (1499/11187) of multi-vehicle collisions involving result in at least one fatal/serious injury. Statistically significant variables for multi-vehicle collision injuries include collision type, light, road surface, junction, road geometry, speed limit, weekend and road type. There was insufficient evidence to suggest that number of vehicles involved, time of day and any interactions were significant.

Model results for multi-vehicle collisions injuries are in agreement with findings for single vehicle 'driver only' and 'driver with passenger' models in the finding that collisions occurring during the hours of darkness were less likely to contain a fatal/serious injury than collisions occurring during daylight and multi-vehicle collisions occurring on a wet road surface were less likely to result in a fatal/serious injury than on dry surface roads. The reason behind the finding of fatal/serious injuries being less likely to have a fatal/serious injury on wet road surface could possibly be explained by drivers driv-

ing more cautiously in wet conditions. Reduced fatal/serious injuries during the hours of darkness may be due to the reduction in the volume of traffic on the roads. Multi-vehicle collisions occurring at the weekend or on a public/bank holiday weekend were more likely to result in a fatal/serious injury and as the number of persons travelling on public holidays/bank holiday weekends is usually greater, this would imply that traffic volume could be an important factor. Unfortunately, traffic volume data is not available for all primary, secondary regions/local roads in Ireland. Similar to the single vehicle 'driver only' model findings, multi-vehicle fatal/serious injuries were more likely to occur as speed limit increased. Fatal/serious injuries were found to be less likely for multi-vehicle collisions on regional roads than national secondary roads, which may possibly be due to the lower speed limit of 80km/h designated to regional/local roads. Multi-vehicle collisions occurring at a junction ear-end/angle collisions were also less likely to result in a fatal/serious injury, rear-end and angle multi-vehicle collisions as opposed to head-on collisions were also less likely to result in a fatal/serious injury, possibly because vehicles are travelling at slower speeds in these collision types than vehicles involved in head-on collisions.

Conditional on the occurrence of a multi-vehicle collision, model results showed that predicted probabilities of a fatal/serious injuries occurring as a result of a multi-vehicle collision differ depending on the type of multi-vehicle collision, as for example a multi-vehicle collision occurring on a national primary road with a speed limit of 100km/h, during daylight hours on a bank holiday weekend, on a hill/gradient, not at a junction, on a dry road surface has a predicted probability of 0.43 (95%CI(0.24,0.66)) for a head-on collision, 0.25 (95%CI(0.11,0.28)) for an angle collision and 0.12 (95%CI(0.05,0.29)) for a rear-end collision

Findings from global road traffic collision models in this study have similar findings to international research which found that time of accident, driver gender and street conditions were significant factors in influencing injury severity in single vehicle collisions [106] and international road traffic collision research has also found that road curvature and vehicle type were also found to be protective in road traffic collisions [77][91][105]. This study provides a unique insight to the conditions surrounding fatal/serious injuries incurred as a result of multi-vehicle/single vehicle collisions in Ireland. Previous studies examining road traffic injuries in Ireland have not specifically examined these collision types.

6.4 Scan Statistics & Global Models

Through the application of scan statistics to all recorded road traffic collisions recorded on Irish roads to detect hot spots/corridors and the application of global model to analyse injuries incurred from different types of road traffic collisions, findings in this study indicate that both approaches provide an overall view of characteristics associated with collision zones and collision injuries. It is important to consider findings from both global models and focused results relating to collision hot spots/corridors using scan statistics as collisions occurring on road collision hot spots/corridors only represent a fraction of collisions and characteristics surrounding collisions at hot spots/corridors may not always agree with findings from the global models, as for example the majority of collisions occurring at collision hot spots/corridors (on national primary and secondary roads) occur on a weekday during the hours of darkness (see p.79, p.81). In contrast findings from global models for both single vehicle collisions and multi-vehicle collisions indicate that conditional of a collision occurrence fatal/serious injuries were more probable on bank-holiday weekends during daylight hours. Thus findings this study highlight the importance of examining global model results in addition to focused scan results, as conditions affecting different road traffic collisions are not necessarily indicative of collisions occurring at road collision hot spots/corridors.

6.5 Limitations

Despite the extensive data available for this research, it was not without limitations. Details relating to traffic volume and actual vehicle speed are not recorded; nor is the use of alcohol/drugs by the driver. Under-reporting of minor collisions is also a cause for concern. Unfortunately there is no unique identifier number that would relate a person involved in a road traffic collision which required medical attention to hospital admission data. Additionally, age/sex of drivers & passengers involved in multi-vehicle collisions (3 or more vehicles) and pedestrians (3 or more) are currently not recorded in the road collision database. Currently, road numbers for regional/local roads are also not recorded in the collision database and before the use of a geographical positioning system (GPS) device (e.g. Garmin, TomTom, SatNav) to record the co-ordinates of a collision location the Garda at the scene of a collision recorded the collision co-ordinates manually with paper maps, which sometimes lead to inaccuracies in grid reference locations. Thus as a result of these data limitations, it is not possible to follow best practice recommendations to develop hierarchical models for road traffic collisions.

Directional data (i.e. the direction of travel for each vehicle involved in the collision) is

another feature of road traffic collisions that is not recorded in the collision data base. The lack of directional data has serious repercussions especially when adopting scan statistics for the identification of road collision hot spots/corridors as it impossible to distinguish which direction the collisions occurred thus leading to difficulty in identifying the location of collision hot spots/corridors e.g. this is of vital importance as collisions occurring in the northbound lane of the M50 motorway should not be combined with collisions occurring on the southbound lane. Thus without the recording of directional data for collisions occurring on motorways/ dual carriage-ways (where lanes are separated by barrier/grass verge) the application of scan statistics to identify collision hot spots/corridors is unrealistic e.g. as combining collisions from northbound & southbound lanes on the M50 will increase collision count thus artificially creating a significant cluster.

Additionally, there are no electronic maps with labelled regional/local roads available. Vector maps provided by the Ordinance Survey do not contain regional/local road number attribute data. Thus the two regional roads that were examined in this study were extracted from electronic maps by tracing the route from paper Ordinance Survey maps. Electronic maps containing speed limit zones for each road are not available for the whole road network. The National Roads Authority (NRA) have maps containing speed limit zones for some national roads, however not all speed zones are kept up-to-date, thus as a result the N81 speed limit zones were manually recorded via a 'GPS' device (e.g. Garmin. TomTom, SatNav) and travelling the road beginning in Dublin City to the end of the road outside of Tullow Co. Carlow. This process would not be recommended for efficient use of time.

It is possible to eliminate the majority of limitations outlined above for both road traffic collision data and road network maps, however the feasibility of some solutions (e.g. unique identifier) is questionable as changes in policy would be required.

6.6 Future Research & Recommendations

The application of variable scan statistics has identified road collision hot spots/corridors on the Irish national road network. If regional/local road maps (with associated road number attributes) were available, it would be possible to run scan statistics on the whole road network in Ireland. Additionally further research is required to examine collisions that are uniformly distributed on a road section, as scan statistics will not identify these collisions as a collision hot spot or collision corridor.

Recording of data relating to age/sex of all drivers/passengers involved in road traffic collisions and road numbers for regional/local roads would enable global multi-vehicle collisions to be extended into hierarchical models as injuries would be nested with colli-

sions and collisions would be nested within individual roads. Additionally, hierarchical single vehicle collisions models with collisions nested within route could also be developed. Further study on collisions involving pedestrians would also be recommended as these collisions are substantially different from single vehicle/multi-vehicle collisions.

National primary roads connect major cities and towns, thus carry large volumes of traffic. Availability of traffic volume data on multiple sections of each national primary road would provide very useful information and could be incorporated into the analysis on road traffic collisions and future work could examine the possibility of using this data in conjunction with the scan statistic analysis for the identification of hot spots/corridors.

Currently the work involved to identify collision hot spots/corridors and associated characteristics with these areas is a very long process which involves multiple procedure repetitions as each road must be completed separately and many steps must be taken before the scan can be run on the data. With the improvement of geo-coordinate accuracy of collisions, electronic maps, collision data and software - future development of a software application to perform all the analysis within the GIS environment would be highly desirable. Unfortunately, with current collision data and maps available this is not yet a possibility.

6.7 Conclusion

This research is set in the context of the latest 5-year road safety strategy (2007 - 2011) which was developed to help reduce of road fatalities and serious injuries in Ireland. Through the application of variable window scan statistics, road traffic collision hot spots and corridors along the national road network in Ireland were identified. Human, environmental and infrastructural characteristics associated with road traffic collisions occurring in these areas were identified. Prior to this research scan statistics have not been utilized to identify road traffic collision hot spots/corridors in Ireland. Additionally, this research explores and suggests a systematic approach to identify multiple collision hot spots/corridors along a linear network. Findings in this study also highlight the importance of examining the underlying distribution of collisions before applying scan statistics because if the underlying distribution of collisions on a particular road (or section of road) is uniform then scan statistics will not identify a collision hot spot/corridor even though these collisions may actually be a collision hot spot/corridor.

Deliverables from this study include a complete analysis of all traffic collisions recorded on individual national primary and secondary roads for the identification of road collision hot spots/corridors via scan statistics. Additionally on condition of collision occurrence, global models were developed to determine explanatory characteristics associated with

fatal/serious injuries as a result of single vehicle/multi-vehicle collisions. Collaboration with key stakeholders such as the Health Service Executive, the Road Safety Authority, National Roads Authority and An Garda Síochana is fundamental to ensuring that all research is brought to the attention of those charged with addressing the unacceptable level of road fatalities and injuries, thus a seminar with all aforementioned stake holders will relay findings from this study. In addition to the seminar, specialist training and provision of software (R-code) will be provided to all relevant parties.

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Appendices

.1 Collision Definitions

Road traffic collision definitions are defined by the Road Safety Authority *

- **Fatal Collisions**

  at least one person is killed as a result of the collision and death occurs within 30 days.

- **Serious Injury**

  an injury for which the person is detained in hospital as an 'in-patient', or any of the following injuries whether or not detained in hospital: fractures, concussion, internal injuries, crushings, severe cuts and lacerations, severe general shock requiring medical treatment.

- **Minor Injury**

  where no deaths or serious injuries occur Minor injury is an injury of a minor character such as a sprain or bruise.

- **Pedal Cycle**

  a two/three wheeled road vehicle fitted with pedals deriving its sole means of propulsion from human power.

- **Motor Cycle**

  any mechanically propelled two-wheeled machine & includes mopeds and motor scooters.

- **Car**

  a passenger road vehicle, other than a motorcycle, seating not more than eight passengers (excluding the driver).

- **Public Service Vehicle**

  A passenger road vehicle having seating accommodation for eight passengers (excluding the driver), and used for the carriage of passengers for reward.

- **Goods Vehicle**

  A road vehicle designed, exclusively or primarily, to carry goods.

*Road Safety Collision Facts 2008 P.50 [235]

- **Other Motor Vehicle**

  Other motor vehicles are miscellaneous types of motor vehicle not falling into any of the main categories (e.g. Agricultural Tractor).

- **Rural Area**

  A rural area is defined as an area where the speed limit zone was greater than 60km/h.

- **Urban Area**

  An urban area is defined as an area where the speed limit was less than or equal to 60km/h.

- **Dark**

  The term 'dark' indicates the hours of darkness which begin 30 minutes after sunset and end 30 minutes before sunrise.

- **Single Vehicle Collision with:**

  A single vehicle collision with 'other' refers to single vehicle collision with a pedestrian or any other fixed object not found in any of the main categories.

- **Road character**

  'other' refers to special road conditions. Special road conditions' refers to geometric design of the road other than Straight/Bend/Hillcrest/Some gradient

.2 Penalty Point System

Table 1: Penalty Point Offences

Offences	Penalty Points on payment	Penalty Points on conviction	Fee (EUR) within 28 days	Fee (EUR) ¿ 28 days
A	m*	5	Court Fine	Court Fine
B	m*	3	Court Fine	Court Fine
C	m*	5	Court Fine	Court Fine
D	m*	5	Court Fine	Court Fine
E	m*	3	Court Fine	Court Fine
F	2	4	60	90
G	2	5	80	120
H	1	3	80	120
I	2	4	80	120
J	2	4	80	120
K	2	4	80	120
L	1	3	80	120
M	2	5	80	120
N	2	5	80	120
O	2	4	80	120
P	1	3	80	120
Q	1	3	80	120
R	1	3	60	90
S	1	3	60	90
T	1	3	60	90
U	1	3	60	90
V	1	3	60	90
W	1	3	60	90
X	1	3	60	90
Y	1	4	80	120
Z	2	5	80	120
A1	2	4	80	120
B1	2	4	80	120
C1	2	4	80	120
D1	1	3	60	90
E1	1	3	60	90
F1	1	3	60	90
G1	1	3	60	90
H1	1	3	60	90
I1	m*	3	Court Fine	Court Fine
J1	m*	5	Court Fine	Court Fine
K1	m*	5	Court Fine	Court Fine

Continued on next page

Table 1 – Penalty Point Offences contd.

Offences	Penalty Points on payment	Penalty Points on conviction	Fee (EUR) within 28 days	Fee (EUR) ¿ 28 days
L1	2	4	80	120
M1	m*	5	Court Fine	Court Fine
N1	2	4	60	90
O1	2	4	60	90
P1	m*	5	Court Fine	Court Fine

m* = Mandatory Court Appearance

Table 2: Offences incurring Penalty Point

Label	Offence
A	Using vehicle (car) without test certificate
B	Driving vehicle before remedying dangerous defect
C	Driving dangerously defective vehicle
D	Using vehicle without certificate of roadworthiness
E	Bridge strikes, etc.
F	Holding a mobile phone while driving
G	Dangerous overtaking
H	Failure to act in accordance with a Garda signal
I	Failure to stop a vehicle before stop sign/stop line
J	Failure to yield right of way at a yield sign/yield line
K	Crossing continuous white line
L	Entry by driver into hatched marked area of roadway e.g. Carriageway reduction lane
M	Failure to obey traffic lights
N	Failure to obey traffic rules at railway level crossing
O	Driving a vehicle on a motorway against the flow of traffic
P	Driving on the hard shoulder on a motorway
Q	Driving a HGV (subject to an ordinary speed limit of 80 kms per hour or less) on the outside lane on a motorway or dual carriageway
R	Failure to drive on the left hand side of the road
S	Failure to obey requirements at junctions, e.g. Not being in the correct lane when turning onto another road
T	Failure to obey requirements regarding reversing of vehicles e.g. Reversing from minor road onto main road
U	Driving on a footpath
V	Driving on a cycle track

Continued on next page

Table 2 – Offences incurring Penalty Points contd.

Label	Offence
W	Failure to turn left when entering a roundabout
X	Driving on a median strip, e.g. Boundary between two carriageways
Y	Failure to stop for school warden sign
NA A1	Failure to leave appropriate distance between you and the vehicle in front
B1	Failure to yield
C1	Driving without reasonable consideration
D1	Failure to comply with mandatory traffic signs at junctions
E1	Failure to comply with prohibitory traffic signs
F1	Failure to comply with keep left/keep right signs
G1	Failure to comply with traffic lane markings
H1	Illegal entry onto a one-way street
I1	Driving a vehicle when unfit
J1	Parking a vehicle in a dangerous position
K1	Breach of duties at an accident
L1	Speeding
M1	Driving without insurance
N1	Failure by Driver to comply with front seat belt requirements
O1	Failure by Driver to comply with rear seat belt requirements for passengers under 17 years
P1	Driver found to be driving carelessly

12 penalty points = Automatic Disqualification

m* = Mandatory Court Appearance

.3 Unit Circle

The underlying concepts of traversing a route can be explained using the unit circle.

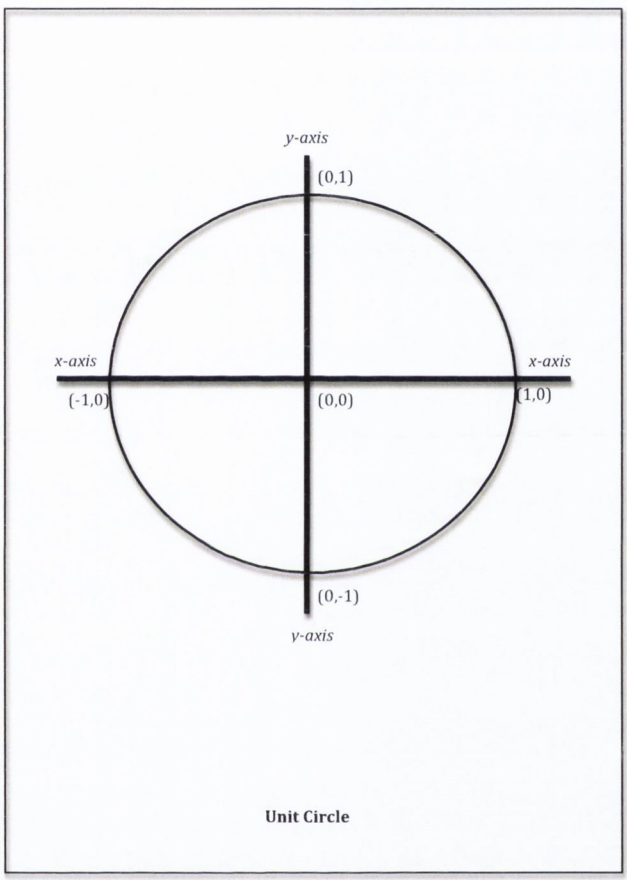


Figure 1: Unit circle

The x-axis and y-axis can denote two routes that intersect at a particular geographical location (0,0) (e.g. In Co.Dublin the N7 national primary route and M50 motorway intersect at the Red Cow Interchange, see section 3.3 for detailed description of the Irish road network). Each route has directional sub-routes within the main route (e.g. the

M50 route has two directional sub-routes: M50 north-bound and M50 south-bound). The unit segment on the x-axis runs from (-1,0) to (1,0) in a positive direction and runs from (1,0) to (-1,0) in a negative direction. (e.g. the N7 runs in an easterly and westerly direction). The unit segment on the y-axis runs in a positive direction (0,-1) to (0,1) and from (0,1) to (0,-1) in a negative direction. (e.g. the M50 runs in an northerly and southerly direction). Examining the different combinations of sub routes based on the unit circle for routes N7(x-axis) and M50 (y-axis) can be seen in table 3.

Table 3: Sub-route combinations

Co-ordinates	Direction on route
	start in the west:
$(-1,0) \rightarrow (0,0) \rightarrow (1,0)$	travel east on N7 for full journey
$(-1,0) \rightarrow (0,0) \rightarrow (0,1)$	travel east on N7 then travel north on M50
$(-1,0) \rightarrow (0,0) \rightarrow (0,-1)$	travel east on N7 then travel south on M50
	start in the east:
$(1,0) \rightarrow (0,0) \rightarrow (-1,0)$	travel west on N7 for full journey
$(1,0) \rightarrow (0,0) \rightarrow (0,1)$	travel west on N7 then travel north on M50
$(1,0) \rightarrow (0,0) \rightarrow (0,-1)$	travel west on N7 then travel south on M50
	start in the north:
$(0,1) \rightarrow (0,0) \rightarrow (0,-1)$	travel south on M50 for full journey
$(0,1) \rightarrow (0,0) \rightarrow (1,0)$	travel south on M50 then travel east on N7
$(0,1) \rightarrow (0,0) \rightarrow (-1,0)$	travel south on M50 then travel west on N7
	start in the south:
$(0,-1) \rightarrow (0,0) \rightarrow (0,1)$	travel north on M50 for full journey
$(0,-1) \rightarrow (0,0) \rightarrow (1,0)$	travel north on M50 then travel east on N7
$(0,-1) \rightarrow (0,0) \rightarrow (-1,0)$	travel north on M50 then travel west on N7

After traversing the route the linear scan statistic (as defined in equation 3.6) is used to identify anomalous windows. The largest linear scan statistic is identified as the anomalous window and Monte Carlo simulations are used to validate this result. The combinatorial approach cannot be applied to Irish road traffic collision data as the travelling direction of vehicles is not recorded in the database (e.g if a collision occurs on the M50, it is unknown if the collision occurred on the north-bound lane or on the south-bound lane).

.4 Appendix GIS

The following lengthy process was repeated for each individual national primary (N1-N32,M50), national secondary (N51-N87 and each of the individual sections which were bounded by national primary roads) and regional roads (R402 and R423).

After running scan statistics on each individual road to identify collision hot spots/corridors the beginning and end co-ordinates of each hot spot and corridor for each road were saved in .txt files associated with each road. These files were read into QGIS and maps which portrayed hot spots and corridors for each road were created.

- **Collision Data into QGIS**
  - Load collision co-ordinate data into GIS software (QGIS)
    - Method: Plugins → delimited text → add delimited text layer. (Collision co-ordinates were stored in a .txt file)
  - Select appropriate co-ordinate reference system (CRS)
    - Method: Layer → properties → general → specify CRS → choose TM65/Irish Grid (EPSG:29902)
  - Save as shape file
- **National Primary and Secondary Road Network into QGIS**
  - Load national roads shape file (received from National Roads Authority (NRA))
    - Method: layer → add vector layer → choose road network file
  - Select appropriate co-ordinate reference system (CRS)
    - Method: Layer → properties → general → specify CRS → choose TM65/Trish Grid (EPSG:29902)
  - Save as shape file
  - Create shape file for each individual route (e.g. N7)
    - Steps: 1) layer → attribute table → choose N7
      2) layer → save selection as shapefile
      (and choose TM65/Irish Grid, EPSG: 29902 as CRS).
- **Manual extraction of Regional Roads into QGIS**
  - Load collisions into QGIS (as outlined above)
  - Load road network map into QGIS (as outlined above)

- Highlight regional road
    - Method: toggle editing → select features → delete selected features (i.e. delete the roads not required)→ when finished deleting routes (not required) click on toggle editing and save result

To calculate the distance of each collision (on individual routes e.g. N7) from start of the road requires the use of GRASS

- **Create New Mapset in GRASS**
    - Create new mapset
        - Steps: 1) plugins → GRASS → New mapset
          2) create new location
          3) Projection TM65/Irish Grid (EPSG:29902)
          4) New mapset "PERMANENT" → Finish

- Load collision data into Grass
    - Method: plugins → GRASS → Open GRASS tools → modules list → v.in.ogr.qgis

- Load route map (e.g. N7) into GRASS
    - Method: Plugins → GRASS → open GRASS tools → modules list → v.in.ogr.qgis

At this point - restart QGIS and load files into GRASS Method:
1) plugins → GRASS → open mapset
2) plugins → GRASS → Add vector layer

Snapping collisions onto the road:

- Add 3 new columns to e.g. N7 collision shape file*
    - Method: plugins → GRASS → open GRASS tools → modules list → v.d.addcol → then type the "name" of the new column followed by "DOUBLE PRECISION"

- Calculate distance of collisions to road (e.g. N7)

*Three new columns: DISTANCE (denotes the distance of the collision from start of road), X1 (denotes the new X co-ordinate of snapped collisions) and Y1 (denotes the new X co-ordinate of snapped collisions)

- Method: plugins → GRASS → open GRASS tools → modules list →v.distance → From: collisions; To: Road; Parameter: minimum distance to nearest feature; Attribute field: Distance
- Repeat for X1 but change Parameter to X
- Repeat for Y1 but change Parameter to Y

- Exclude all collisions snapped greater than 100 meters
  - Method: plugins → GRASS → open GRASS tools → modules list →v.extract.where → Name: collisions; Where: Distance< 100; Name: write new name for file

Calculate distance of each collision from start of route

- Add new column called cdist (to denote the calculated distance) to the e.g. N7 collision shape file
  - Step: plugins → GRASS → open GRASS tools → modules list →v.db.addcol
- Clean route (i.e. to eliminate gaps on the route) e.g. N7
  - Step: 1) plugins → GRASS → open GRASS tools → modules list →v.clean.snap → Threshold = +100
    2) plugins → GRASS → open GRASS tools → modules list →v.clean.break
- Calculate length of route (e.g. N7 road)
  - Step: 1) Create a new column called "Length"
    plugins → GRASS → open GRASS tools → modules list →v.db.addcol Step
    2) Run script to calculate the length of the N7 road: plugins → GRASS → open GRASS tools → shell Type script into shell:
    echo "select Length from N7" — db.select — awk 'x+=$1 ENDprint x' Step
    3) Alternative approach to calculate length of N7 road
    Open the N7 road .dbf file in OpenOffice and sum the Length column
- Run script to calculate the distance of each collision to the star of the road
  - Step 1) identify the co-ordinates of the start of the road by hovering the cursor over the location and read off the co-ordinates
    Step 2) Run script to calculate distance of each collision from start of road *

*GRASS script to calculate the distance of individual points from beginning of a line (road) was written by O. Dassau, GBD-consult, Hanover, Germany; http://www.gbd-consult.de

Script:

Notes

< *roadmap* >: cleaned roadmap used for network analysis

< *collmap* >: map with collision point coordinates

< *colname* >: column name where results are added

< *endcoordinate* >: end coordinate of the network analysis

create variables

```
ROADMAP=$1
COLLMAP=$2
COLNAME=$3
ENDCOOR= "echo "$4" — tr -s ',' '—"'
```

we do the analysis in a for-loop for all collision points in the map

```
for i in 'echo "SELECT cat FROM $COLLMAP" — db.select -c –q'; do
```

another variable used inside the for-loop

```
COLLCOOR='echo "SELECT X1,Y1 FROM $COLLMAP WHERE cat=$i" — db.select
-c –q'
```

create vector layer with start and end coordinate

```
echo " $i—$COLLCOOR—start 2—$ENDCOOR—end" — v.in.ascii cat=1 X1=2 Y1=3
out=startend
col= "cat int,  east double precision, north double precision, label varchar(20)" –q
```

create lines map connecting start and end coordinate to the road network

```
v.net $ROADMAP points = startend out = $ROADMAPstartend op=connect
thres=100000 –q
```

add length of shortest path and add it to the attribute table

```
DISTANCE='echo "SELECT cost FROM path" — db.select -c –q'
echo "Distance from collision point $i to start coordinate is $DISTANCE meters"
echo "UPDATE $COLLMAP SET $COLNAME=$DISTANCE WHERE cat=$i" — db.execute
–q
```

cleanup temporary maps

```
g.mremove -f vect=$ROADMAPstartend,startend,path –q

    done

    echo “finished”
echo “values are added to column $COLNAME in layer $COLLMAP”

    exit 0
```

After the distance for each collision to the beginning of the road is completed, the scan statistic is used to identify hot spots. The algorithm for the variable window scan statistic, as given by Nagarwalla, is as follows:
Let $x_l, ..., x_N$ be the observed values of the data, in increasing order.
For each $n = n_o, ..., N_{-2}$
For each $i = 1, ..., N - n + 1$
Find: $(x_{i+n-1} - x_i)$
Let $d_{min}[n] = min_i(x_{i+n-1} - xi)$
, $i_{min}[n] = i : d_{min}[n] = (x_{i+n-1} - xii)$
Find $\lambda[n] = (\frac{n}{N})^n(\frac{N-n}{N})^{N-n}(\frac{1}{d_{min}})^n(\frac{1}{1-d_{min}})^{N-n}$
Let $\lambda* = max_n\lambda[n]$ and let n* and i* be the values of n and i for which this maximum is achieved. The most likely cluster begins at the i*th observation and consists of the n* points $x_{i*}..., x_{i*+n*-1}$. The observed value of the likelihood ratio for the data is $\lambda*$.

Original research by Nagarwalla was based on temporal data of the birth defects oesophageal atresia and tracheo-oesophageal fistula observed in a hospital in Birmingham, U.K., between 1950 and 1955. This research adapts distance (km) along a linear network (road) as distinct from distance (days) in (linear) time.

.5 Bernoulli Models

A retrospective temporal analysis using the Bernoulli model (as outlined in chapter 3, section 3.1.5, P.48) was applied to all road traffic collisions recorded from 1st January 2005 - 31st December 2009 for each of the cities in Ireland: Dublin, Cork, Limerick, Waterford and Galway. Fatal/serious road traffic collisions were denoted as cases and minor collisions were denoted as controls. Tables 4-6 in

.5.1 Dublin City

A total of 3,628 road traffic collisions were recorded in Dublin City. Approximately 9% (314/3628) of these collisions were fatal/serious collisions. Table 4 shows the results Cities of Dublin, Limerick and Waterford.

Table 4: Bernoulli Model - Dublin City

Output	
Location IDs included	all
Population	444
Number of cases	59
Expected cases	38.43
Observed / expected	1.54
Relative Risk	1.66
Log likelihood ratio	6.12
P-value	0.16
Time frame	4/2/05 - 6/10/05

.5.2 Limerick City

A total of 557 road traffic collisions were recorded in Limerick City. Approximately 6% (32/557) of these collisions were fatal/serious collisions. Table 5 shows the results of the most likely cluster for Limerick City.

Table 5: Bernoulli Model - Limerick City

Output	
Location IDs included	all
Population	3
Number of cases	2
Expected cases	0.17
Observed / expected	11.60
Relative Risk	12.31

Continued on next page

Table 5 – Bernoulli Model - Limerick City contd.

Output	
Log likelihood ratio	3.92
P-value	0.64
Time frame	28/1/05 - 10/2/05

.5.3 Waterford City

A total of 306 road traffic collisions were recorded in Waterford City. Approximately 7% (22/306) of these collisions were fatal/serious collisions. Table 6 shows the results of the most likely cluster for Waterford City.

Table 6: Bernoulli Model - Waterford City

Output	
Location IDs included	all
Population	2
Number of cases	2
Expected cases	0.14
Observed / expected	13.91
Relative Risk	15.20
Log likelihood ratio	5.35
P-value	0.22
Time frame	7/1/05 - 27/1/05

.6 Space Time Models

As discussed in section 3.1.6 the space time permutation model compares the number of observed number of cases in a cluster with the number of cases that would have been expected if the spatial and temporal locations of all cases were independent of each other so that there is no space time interaction [232].

A retrospective analysis using the space time permutation model was applied to all road traffic collisions recorded from 1st January 2005 - 31st December 2009 for each of the cities in Ireland Tables 7 - 10 show results for cities Cork, Limerick, Galway and Waterford .

.6.1 Cork City

A total of 905 road traffic collisions were recorded in Cork City. Table 7 show the results for the most likely cluster identified in Cork city. As this cluster is not significant a graphical representation of the cluster is not given. Additionally, there were no significant secondary clusters identified.

Table 7: Space Time Permutation Model - Cork City

Output	
Radius	750.64
Number of cases	5
Expected cases	0.22
Observed / expected	23.06
Test statistic	10.92
P-value	0.52
Time frame	13/1/06 - 26/1/06

.6.2 Limerick City

A total of 557 road traffic collisions were recorded in Limerick City. Table 8 show the results for the most likely cluster identified in Limerick. As this cluster is not significant a graphical representation of the cluster is not given. Additionally, there were no significant secondary clusters identified.

Table 8: Space Time Permutation Model - Limerick City

Output	
Radius	870.83
Number of cases	5
Expected cases	0.26

Continued on next page

Table 8 – Space Time Permutation Model - Limerick City contd.

Output	
Observed / expected	19.48
Test statistic	10.12
P-value	0.42
Time frame	7/1/05 - 10/2/05

.6.3 Galway City

A total of 374 road traffic collisions were recorded in Galway City. Table 9 show the results for the most likely cluster identified in Galway. As this cluster is not significant a graphical representation of the cluster is not given. Additionally, there were no significant secondary clusters identified.

Table 9: Space Time Permutation Model - Galway City

Output	
Radius	338.96
Number of cases	3
Expected cases	0.04
Observed / expected	70.31
Test statistic	9.81
P-value	0.20
Time frame	3/10/08 - 9/10/08

.6.4 Waterford City

A total of 306 road traffic collisions were recorded in Waterford City. Table 10 show the results for the most likely cluster identified in Waterford. As this cluster is not significant a graphical representation of the cluster is not given. Additionally, there were no significant secondary clusters identified.

Table 10: Space Time Permutation Model - Waterford City

Output	
Radius	311.11
Number of cases3	3
Expected cases	0.09
Observed / expected	34.22
Test statistic	7.20
P-value	0.89
Time frame	10/6/05 - 23/6/05

.7 Collision Hot Spots/Corridors: National Primary Roads

The N1/M1 national primary road runs from Dublin city centre to the border in Northern Ireland just south of Newry, Co. Antrim to connect Dublin to Newry and Lisburn via the A1 and M1. Two hundred and forty two road traffic collisions were recorded on the N1/M1 road from 2005-2009. The scan statistic was run on 163 road traffic collisions as collisions with geographical coordinates located more than 100m from the M1/N1 road were excluded from the analysis. Two clusters were identified, and Table 11 gives detailed description of each cluster. A geographical representation of the clusters can be seen in the map: M1/N1 hot spots and corridors.

- **Cluster 1**
  - Location: M1/M50 interchange
  - Number of collisions: 11
  - Length: 1.4km

Approximately 63.6% (7/11) of the collisions recorded in cluster 1 were multi-vehicle collisions. All recorded collisions occurred during the hours of darkness and 72.7% (8/11) occurred on a weekday. Approximately 81.8% (8/11) occurred on a dry road surface and 54.5% (6/11) occurred on sections of road with speed limits 80km/h and below. The majority of injuries sustained were minor injuries, one serious injury and zero fatalities were recorded in this cluster.

- **Cluster 2**
  - Location: Swords Road (Griffith Avenue) - Parnell Street, Dublin City
  - Number of collisions: 56
  - Length: 3.1km

Approximately 33.9% (19/56) of the collisions recorded in cluster 2 were pedestrian involved collisions and 35.7%(20/56) were multi-vehicle collisions. Ninety two (52/56) of collisions recorded occurred during the hours of darkness and 82.1% (46/56) occurred on a weekday. Approximately 71.4% (40/56) occurred on a dry road surface, 48.2% (27/56) occurred at a junction and 98.2% (55/56) occurred on sections of road with speed limits 60km/h and below. The majority of injuries sustained were minor injuries, two serious injuries and one fatality were recorded in this cluster.

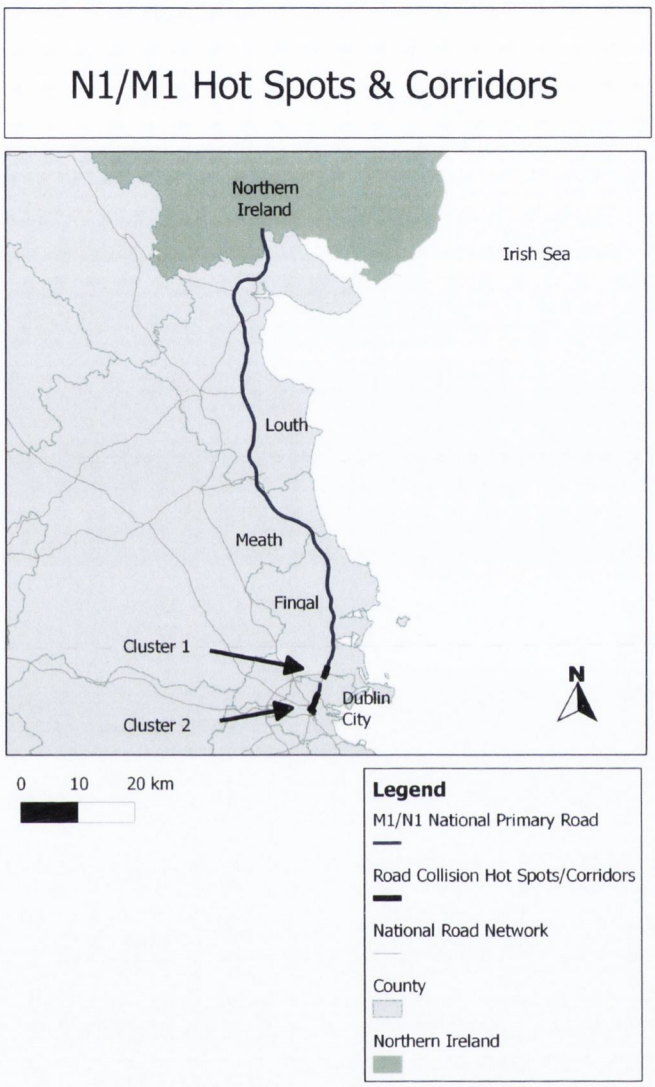


Figure 2: M1/N1 Collision Hot Spots/Corridors

Table 11: N1/M1 Road Collision Hot Spots/Corridors

Description	Cluster 1	Cluster 2
Number of Collisions	11	56
Collision Type		
Pedestrian	0	19
Single Vehicle	3	1
Head-on	0	5
Angle	2	8
Rear-end	5	7
Unknown	1	16
Light		
Hours of daylight	0	0
Hours of darkness	11	52
Unknown	0	4
Day		
Weekday	8	46
Weekend	2	9
Bank holiday weekend	1	1
Road Surface		
Dry	9	40
Wet	1	10
Other/Unknown	1	6
Junction		
Yes	3	27
No	8	29
Speed Limit		
$\leq$ 60 km/h	3	55
80km/h	3	0
100km/h	0	1
120km/h	5	0
Injuries		
Fatal	0	1
Serious	1	2
Minor	11	66
Not Injured/Unknown	0	2

The N3 connects Dublin City to Ballyshannon, Co. Donegal via Enniskillen, Co. Tyrone (Northern Ireland) via the A509, A32 & A46. Three hundred and seventy one road traffic collisions were recorded on the N3 road from 2005-2009. The scan statistic was run on 358 road traffic collisions as collisions with geographical coordinates located more than 100m from the N3 road were excluded from the analysis. Due to the large portion of the N3 road segmented by Northern Ireland, it was necessary to run the scan on the two parts of the N3 separately. No significant clusters were identified on Ballyshannon, Co. Donegal to the Northern Ireland border at the A46 (Loughshore Road). Five clusters were identified on the Dublin City to Northern Ireland border at A509 (Belturbet Road). Table 12 gives detailed description of each cluster. A geographical representation of the clusters can be seen in the map: N3 hot spots and corridors.

- **Cluster 1**
  - Location: North West of Blackbull, Co. Meath
  - Number of collisions: 15
  - Length: 183m

Approximately 80% (12/15) of the collisions recorded in cluster 1 were multi-vehicle collisions. Seventy three percent (11/15) collisions recorded occurred during the hours of darkness and 73.3% (11/15) occurred on a weekday. Approximately 73.3% (11/15) occurred on a dry road surface and 66.7% (10/15) occurred at a junction and 86.7% (13/15) occurred on sections of road with speed limits 100km/h. Twenty of the reported injuries sustained were minor, zero serious injuries and one fatality were recorded in this cluster.

- **Cluster 2**
  - Location: North West of Cooksland, Co. Meath - Main Street Dunsaughlin, Co. Meath
  - Number of collisions: 24
  - Length: 1.6km

Approximately 54.2% (13/24) of the collisions recorded in cluster 2 were multi-vehicle collisions. Ninety six percent (23/24) of collisions recorded occurred during the hours of darkness and 75% (18/24) occurred on a weekday. Approximately 45.8% (11/24) occurred on a dry road surface, 29.2% (7/24) occurred at a junction and 83.3% (20/24) occurred on sections of road with speed limit 60km/h or below. Twenty four of the injuries sustained were minor injuries, two serious injuries and two fatalities were recorded in this cluster.

- **Cluster 3**
  - Location: South East of Annagelliff, Co. Cavan - Dublin Road, Co. Cavan
  - Number of collisions: 7
  - Length: 134m

Approximately 42.9% (3/7) of the collisions recorded in cluster 3 were multi-vehicle collisions. Eighty six percent (6/7) of collisions recorded occurred during the hours of darkness and 42.9% (3/7) occurred on a weekday. Approximately 42.9% (3/7) occurred on a dry road surface, 57.1% (4/7) occurred at a junction and 85.7% (6/7) occurred on sections of road with speed limit 100km/h. Eight of the injuries sustained were minor, zero serious injuries and zero fatalities were recorded in this cluster.

- **Cluster 4**
  - Location: South of Ross (Ed Tara), Co. Meath
  - Number of collisions: 6
  - Length: 137m

All of the collisions recorded in cluster 4 were multi-vehicle collisions. Eighty three percent (5/6) of collisions recorded occurred during the hours of darkness and 50% (3/6) occurred on a weekday. Approximately 50% (3/6) occurred on a dry road surface, 66.7% (4/6) occurred at a junction and all collisions recorded occurred on sections of road with speed limit 100km/h. Seven of the injuries sustained were minor injuries, one serious injury and one fatality were recorded in this cluster.

- **Cluster 5**
  - Location: Navan Road Co. Dublin - North Circular Road/Phibsborough Road intersection, Dublin City
  - Number of collisions: 30
  - Length: 2.7km

Approximately 46.7% (14/30) of the collisions recorded in cluster 5 were multi-vehicle collisions and 30% (9/30) are pedestrian involved collisions. Ninety three percent (28/30) of collisions recorded occurred during the hours of darkness and 83.3% (25/30) occurred on a weekday. Approximately 56.7% (17/30) occurred on a dry road surface, 46.7% (14/30) occurred at a junction and all collisions recorded occurred on sections of road

with speed limit 60km/h and below. Thirty seven of the injuries sustained were minor injuries, zero serious injuries and two fatalities were recorded in this cluster.

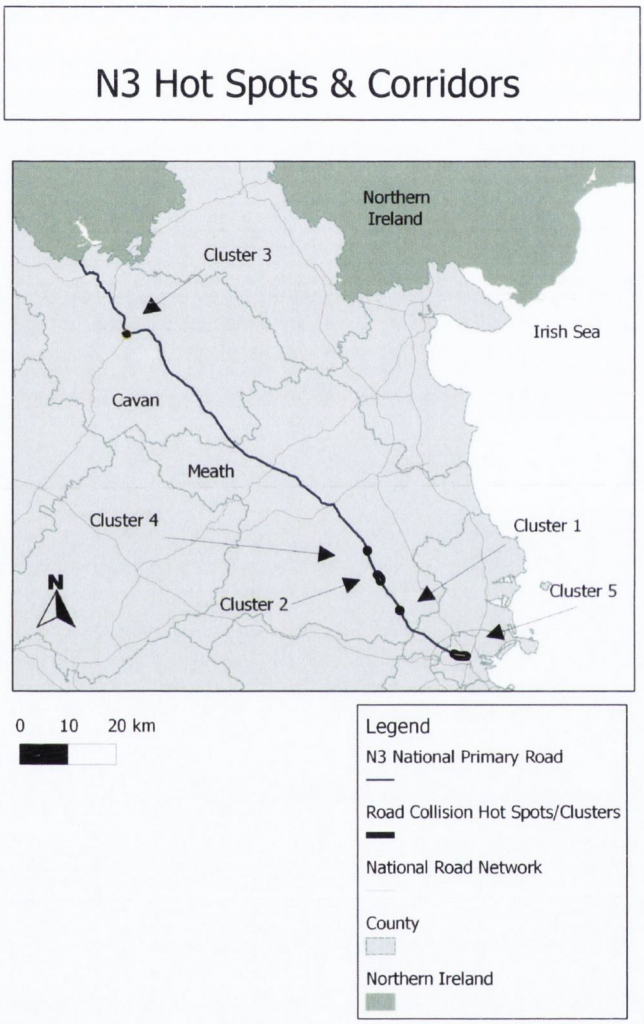


Figure 3: N3 Collision Hot Spots/Corridors

Table 12: N3 Road Collision Hot Spots/Corridors

Description	Cluster 1	Cluster 2	Cluster 3	Cluster 4	Cluster 5
Number of Collisions	15	24	7	6	30
Collision Type					
Pedestrian	0	6	0	0	9
Single Vehicle	1	3	2	0	0
Head-on	2	2	0	1	0
Angle	8	4	2	4	7
Rear-end	2	7	1	1	7
Unknown	2	2	2	0	7
Light					
Hours of daylight	4	1	0	1	0
Hours of darkness	11	23	6	5	28
Unknown	0	0	1	0	2
Day					
Weekday	11	18	3	3	25
Weekend	4	6	4	1	5
Bank holiday weekend	0	0	0	2	0
Road Surface					
Dry	11	11	3	3	17
Wet	4	10	3	3	8
Other/Unknown	0	3	1	0	5
Junction					
Yes	10	7	4	4	14
No	5	17	3	2	16
Speed Limit					
$\leq$ 60 km/h	2	20	6	0	30
80km/h	0	0	0	0	0
100km/h	13	4	0	6	0
120km/h	0	0	1	0	0
Injuries					
Fatal	1	2	0	1	2
Serious	0	2	0	1	0
Minor	22	24	8	7	37
Not Injured/Unknown	2	3	0	1	0

The N4 connects Dublin City to Sligo. Three hundred and ninety one road traffic collisions were recorded on the N4 road from 2005-2009. The scan statistic was run on 358 road traffic collisions as collisions with geographical coordinates located more than 100m from the N4 road were excluded from the analysis. Two clusters were identified, and Table 13 gives detailed description of each cluster. A geographical representation of the clusters can be seen in the map: N4 hot spots and corridors.

- **Cluster 1**
  - Location: Leixlip Road, North West of Celbridge Road Interchange, Co. Dublin - Aston Quay/Westmoreland Street intersection, Dublin City
  - Number of collisions: 112
  - Length: 14.7km

Approximately 60.7% (68/112) of the collisions recorded in cluster 1 were multi-vehicle collisions. Ninety three percent (108/112) collisions recorded occurred during the hours of darkness and 73.2% (82/112) occurred on a weekday. Approximately 62.5% (70/112) occurred on a dry road surface, 44.6% (50/112) occurred at a junction and 58.9% (66/112) occurred on sections of road with speed limits 60km/h and below. One hundred and thirty one of injuries sustained were minor injuries, eight serious injuries and three fatalities were recorded in this cluster.

- **Cluster 2**
  - Location: North West of Ballymahon Rd, Co. Longford - Ballymahon Road, Edgeworthstown, Co. Longford
  - Number of collisions: 14
  - Length: 1.1km

Approximately 71.4% (10/14) of the collisions recorded in cluster 2 were multi-vehicle collisions. All collisions recorded occurred during the hours of darkness and 64.3% (9/14) occurred on a weekday. Approximately 50% (7/14) occurred on a dry road surface, 0.14% (2/14) occurred at a junction and 50% (7/14) occurred on sections of road with speed limit 60km/h or less. Fifteen of the injuries sustained were minor injuries, two serious injuries and zero fatalities were recorded in this cluster.

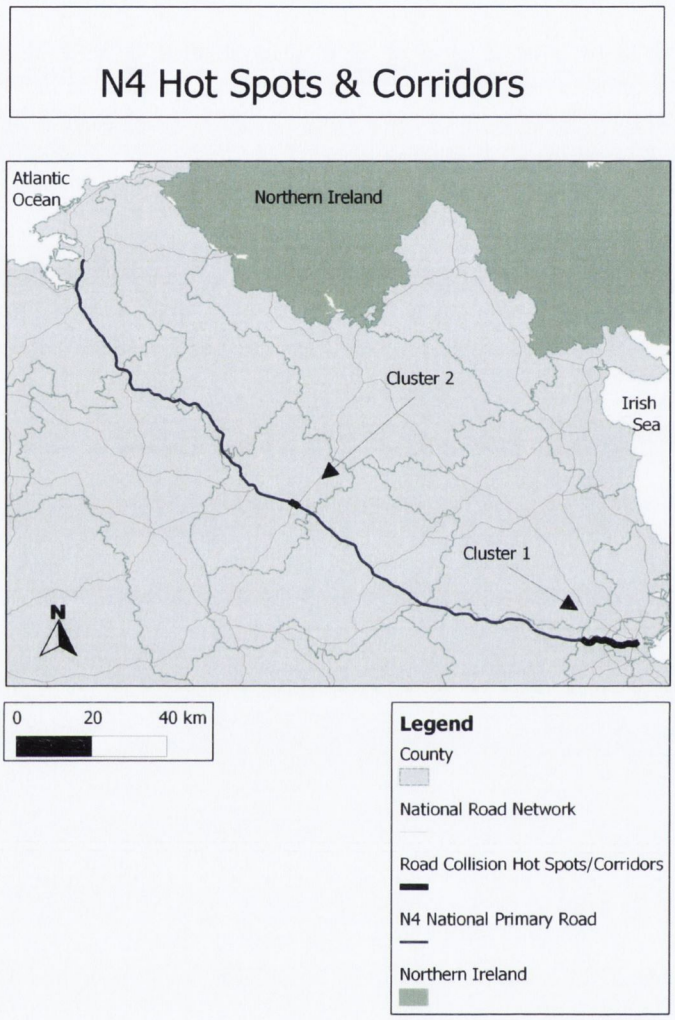


Figure 4: N4 Collision Hot Spots/Corridors

Table 13: N4 Road Collision Hot Spots/Corridors

Description	Cluster 1	Cluster 2
Number of Collisions	112	14
Collision Type		
Pedestrian	16	1
Single Vehicle	8	1
Head-on	6	1
Angle	15	3
Rear-end	47	7
Unknown	20	1
Light		
Hours of daylight	1	0
Hours of darkness	108	14
Unknown	3	
Day		
Weekday	82	9
Weekend	25	5
Bank holiday weekend	5	0
Road Surface		
Dry	70	7
Wet	34	7
Other/Unknown	8	0
Junction		
Yes	50	2
No	62	12
Speed Limit		
$\leq$ 60 km/h	66	7
80km/h	23	1
100km/h	22	6
120km/h	1	0
Injuries		
Fatal	3	0
Serious	8	2
Minor	131	15
Not Injured/Unknown	14	0

The N5 connects Longford town, Co. Longford to Westport, Co. Mayo. One hundred and ninety five road traffic collisions were recorded on the N5 road from 2005-2009. The scan statistic was run on 173 road traffic collisions as collisions with geographical coordinates located more than 100m from the N5 road were excluded from the analysis. One cluster was identified, and Table 14 gives detailed description of this cluster. A geographical representation of the clusters can be seen in the map: N5 hot spots and corridors.

- **Cluster 1**
  - Location: West of Cloggernagh East, Co. Mayo - Bridge Street, Westport, Co. Mayo
  - Number of collisions: 33
  - Length: 9.9km

Approximately 54.5% (18/33) of the collisions recorded in cluster 1 were multi-vehicle collisions. Seventy percent (23/33) collisions recorded occurred during the hours of darkness and 54.5% (18/33) occurred on a weekday. Approximately 48.5% (16/33) occurred on a dry road surface, 18.1% (6/33) occurred at a junction and 72.7% (24/33) occurred on sections of road with speed limits 100km/h. Forty four of injuries sustained were minor injuries, eight serious injuries and one fatality were recorded in this cluster.

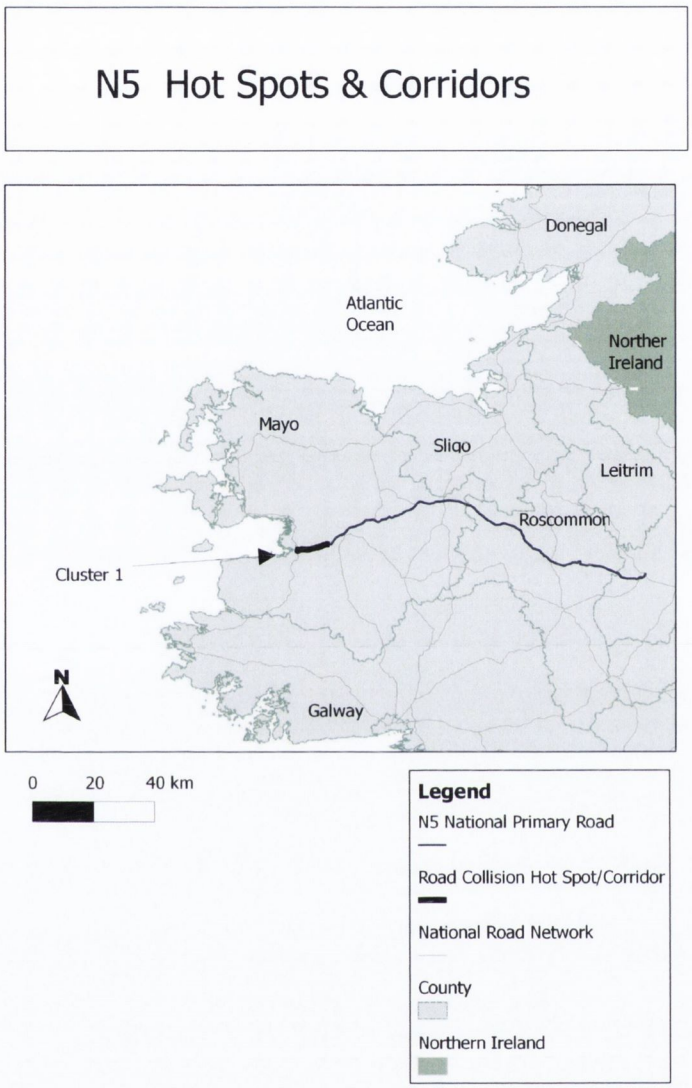


Figure 5: N5 Collision Hot Spots/Corridors

Table 14: N5 Road Collision Hot Spots/Corridors

Description	Cluster 1
Number of Collisions	33
Collision Type	
Pedestrian	5
Single Vehicle	2
Head-on	3
Angle	4
Rear-end	11
Unknown	5
Light	
Hours of daylight	9
Hours of darkness	23
Unknown	1
Day	
Weekday	18
Weekend	14
Bank holiday weekend	1
Road Surface	
Dry	16
Wet	14
Other/Unknown	3
Junction	
Yes	6
No	27
Speed Limit	
$\leq$ 60 km/h	7
80km/h	2
100km/h	24
120km/h	0
Injuries	
Fatal	1
Serious	8
Minor	44
Not Injured/Unknown	2

The N6 connects Kinnegad, Co. Westmeath to Galway City, Co. Galway. Two hundred and thirty eight road traffic collisions were recorded on the N6/M6 road from 2005-2009. The scan statistic was run on 75 road traffic collisions as collisions with geographical coordinates located more than 100m from the N6 road were excluded from the analysis. Three clusters were identified, and Table 15 gives detailed description of each cluster. A geographical representation of the clusters can be seen in the map: N6 hot spots and corridors.

- **Cluster 1**
  - Location: Dun Na Coiribe, West of Bodkin Roundabout, Galway, Co. Galway - Headford Road, Galway, Co. Galway.
  - Number of collisions: 7
  - Length: 465m

All of the collisions recorded in cluster 1 were pedestrian involved collisions. All collisions recorded occurred during the hours of darkness and 85.7% (6/7) occurred on a weekday. Approximately 57.1% (4/7) occurred on a dry road surface, 57.1% (4/7) occurred at a junction and all collisions recorded occurred on sections of road with speed limits 60km/h and below. Seven of injuries sustained were minor injuries, one serious injury and zero fatalities were recorded in this cluster.

- **Cluster 2**
  - Location: Athlone bypass, Co. Westmeath - Dublin Road, Co. Westmeath
  - Number of collisions: 19
  - Length: 7.5km

Approximately 47.4% (9/19) of the collisions recorded in cluster 2 were multi-vehicle collisions. Eighty four percent (16/19) of collisions recorded occurred during the hours of darkness and 73.7% (14/19) occurred on a weekday. Approximately 78.9% (15/19) occurred on a dry road surface, 15.8% (3/19) occurred at a junction and 89.5% (17/19) of collisions recorded occurred on sections of road with speed limits 100km/h. Twenty eight of injuries sustained were minor injuries, one serious injury and two fatalities were recorded in this cluster.

- **Cluster 3**
  - Location: South West of BallyDangan Co. Roscommon - South west of Toberiheen, Co. Roscommon (Now labelled R446 road)

- Number of collisions: 9
- Length: 1.1km

Approximately 55.6% (5/9) of the collisions recorded in cluster 3 were multi-vehicle collisions and 44.4% (4/9) were single vehicle collisions. Forty four percent (5/9) of collisions recorded occurred during the hours of darkness and 77.8% (7/9) occurred on a weekday. Approximately 66.7% (6/9) occurred on a dry road surface, 22.2% (2/9) occurred at a junction and 66.7% (6/9) of collisions recorded occurred on sections of road with speed limits 100km/h. Nine of injuries sustained were minor injuries, three serious injuries and zero fatalities were recorded in this cluster.

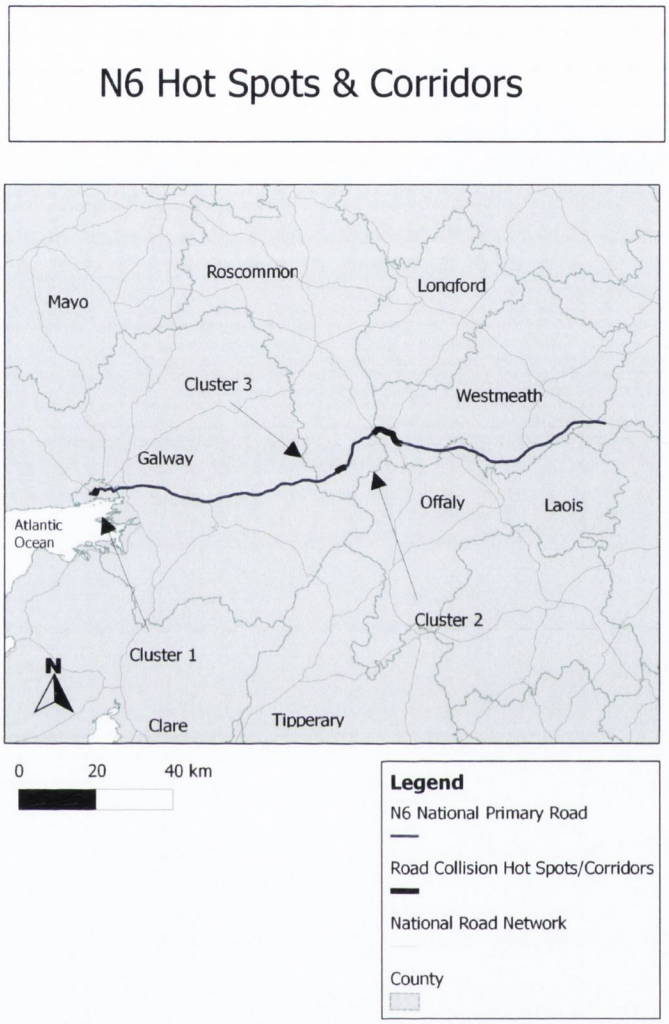


Figure 6: N6 Collision Hot Spots/Corridors

Table 15: N6 Road Collision Hot Spots/Corridors

Description	Cluster 1	Cluster 2	Cluster 3
Number of Collisions	7	19	9
Collision Type			
Pedestrian	7	0	0
Single Vehicle	0	7	4
Head-on	0	3	1
Angle	0	1	4
Rear-end	0	5	0
Unknown	0	3	0
Light			
Hours of daylight	0	3	5
Hours of darkness	7	16	4
Unknown	0	0	
Day			
Weekday	6	14	7
Weekend	1	5	2
Bank holiday weekend	0	0	0
Road Surface			
Dry	4	15	6
Wet	3	4	2
Other/Unknown	0	0	1
Junction			
Yes	4	3	2
No	3	16	7
Speed Limit			
$\leq$ 60 km/h	7	1	0
80km/h	0	1	1
100km/h	0	17	6
120km/h	0	0	2
Injuries			
Fatal	0	2	0
Serious	1	1	3
Minor	7	28	9
Not Injured/Unknown	0	1	0

The N7 connects Dublin City to Limerick City, Co. Limerick. Three hundred and seventy road traffic collisions were recorded on the N7/M7 road from 2005-2009. The scan statistic was run on 300 road traffic collisions as collisions with geographical coordinates located more than 100m from the N7 road were excluded from the analysis. Three clusters were identified, and Table 16 gives detailed description of each cluster. A geographical representation of the clusters can be seen in the map: N7 hot spots and corridors.

- **Cluster 1**
  - Location: Newlands Cross, Lucan
  - Number of collisions: 7
  - Length: 43m

Approximately 71.4% (5/7) of the collisions recorded in cluster 1 were multi-vehicle collisions. All collisions recorded occurred during the hours of darkness and 57.1% (4/7) occurred on a weekday. Approximately 57.1% (4/7) occurred on a dry road surface, 71.4% (5/7) occurred at a junction and all collisions recorded occurred on sections of road with speed limits 80km/h and below. Nine of injuries sustained were minor injuries, zero serious injuries and one fatality were recorded in this cluster.

- **Cluster 2**
  - Location: South West of Daly's Cross, Castleconnell, Co. Limerick - Dublin Road, Co. Limerick
  - Number of collisions: 11
  - Length: 574m

Approximately 63.6% (7/11) of the collisions recorded in cluster 2 were multi-vehicle collisions. All collisions recorded occurred during the hours of darkness and 81.8% (9/11) occurred on a weekday. Approximately 36.3% (4/11) occurred on a dry road surface, 72.7% (8/11) occurred at a junction and 90.9% (17/19) of collisions recorded occurred on sections of road with speed limits 100km/h. Sixteen of injuries sustained were minor injuries, zero serious injuries and one fatality were recorded in this cluster.

- **Cluster 3**
  - Location: M7 (Naas Road) - West of Newlands Cross, Co. Dublin
  - Number of collisions: 65
  - Length: 22.1km

Approximately 55.4% (36/65) of the collisions recorded in cluster 3 were multi-vehicle collisions and 30.8% (20/65) were single vehicle collisions. Three percent (2/65) of collisions recorded occurred during the hours of darkness and 73.8% (48/65) occurred on a weekday. Approximately 55.3% (36/65) occurred on a dry road surface, 13.8% (9/65) occurred at a junction and 44.6% (29/65) of collisions recorded occurred on sections of road with speed limits 100km/h. Sixty four of injuries sustained were minor injuries, seventeen serious injuries and six fatalities were recorded in this cluster.

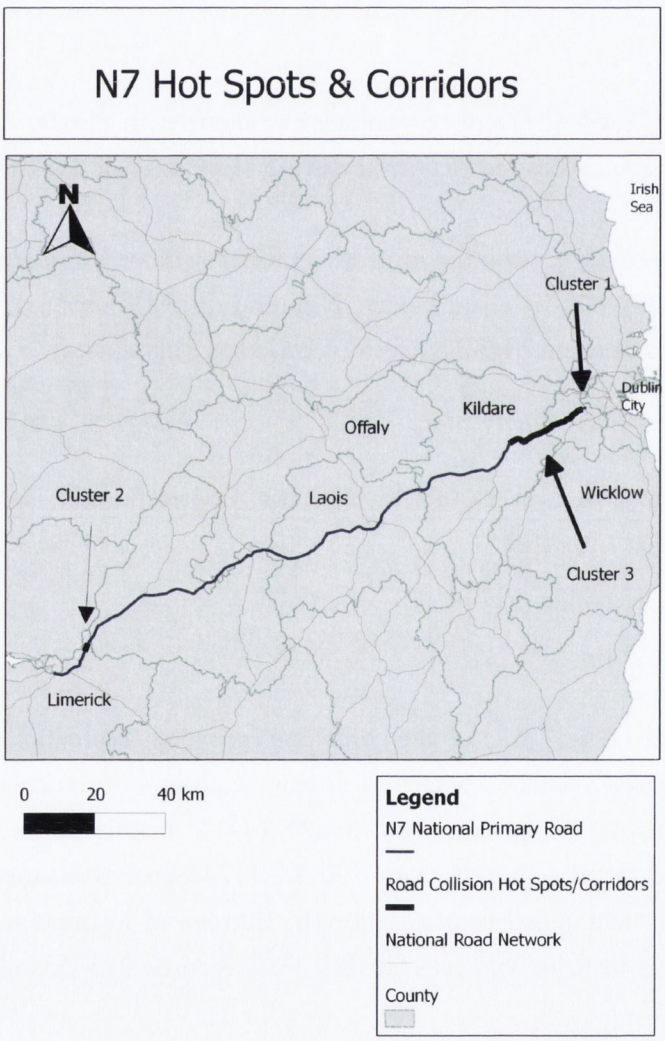


Figure 7: N7 Collision Hot Spots/Corridors

Table 16: N7 Road Collision Hot Spots/Corridors

Description	Cluster 1	Cluster 2	Cluster 3
Number of Collisions	7	11	65
Collision Type			
Pedestrian	0	1	2
Single Vehicle	1	0	20
Head-on	1	0	3
Angle	2	2	7
Rear-end	2	5	26
Unknown	1	0	7
Light			
Hours of daylight	0	0	58
Hours of darkness	7	11	2
Unknown	0	0	5
Day			
Weekday	4	9	48
Weekend	3	2	17
Bank holiday weekend	0	0	0
Road Surface			
Dry	4	4	36
Wet	3	7	23
Other/Unknown	0	0	6
Junction			
Yes	5	8	9
No	2	3	56
Speed Limit			
$\leq$ 60 km/h	4	1	15
80km/h	3	0	7
100km/h	0	10	29
120km/h	0	0	14
Injuries			
Fatal	1	1	6
Serious	0	0	17
Minor	9	16	64
Not Injured/Unknown	1	0	8

The N8 is the primary road to Cork City, Co. Cork, which begins at the M7/M8 interchange at junction 19. Pre-2010 the N8 (now called the N77) started at the M7 Portlaoise interchange at junction 17, Co. Laois. Two hundred and seventy two road traffic collisions were recorded on the N8/M8 road from 2005-2009. The scan statistic was run on 190 road traffic collisions as collisions with geographical coordinates located more than 100m from the N8 road were excluded from the analysis. Two clusters were identified, and Table 17 gives detailed description of each cluster. A geographical representation of the clusters can be seen in the map: N8 hot spots and corridors.

- **Cluster 1**
  - Location: N8/N22 (St. Patrick's St Bridge), Co. Cork - North East of Richmond, Co. Cork
  - Number of collisions: 38
  - Length: 6.5km

Approximately 34.2% (13/38) of the collisions recorded in cluster 1 were multi-vehicle collisions. All collisions recorded occurred during the hours of darkness and 68.4% (26/38) occurred on a weekday. Approximately 55.3% (21/38) occurred on a dry road surface, 36.8% (14/38) occurred at a junction and 89.5% (34/38) collisions recorded occurred on sections of road with speed limits 80km/h and below. Thirty eight of injuries sustained were minor injuries, three serious injuries and two fatalities were recorded in this cluster.

- **Cluster 2**
  - Location: Main Street, Abbeyleix, Co. Laois (Now Named N77) - South of Corbally, Co. Laois
  - Number of collisions: 25
  - Length: 2.9km

Approximately 52% (13/25) of the collisions recorded in cluster 2 were multi-vehicle collisions. Ninety two collisions recorded occurred during the hours of darkness and 68% (17/25) occurred on a weekday. Approximately 48% (12/25) occurred on a dry road surface, 24% (6/25) occurred at a junction and 23.1% (15/25) of collisions recorded occurred on sections of road with speed limits 100km/h. Thirty of injuries sustained were minor injuries, ten serious injuries and two fatalities were recorded in this cluster.

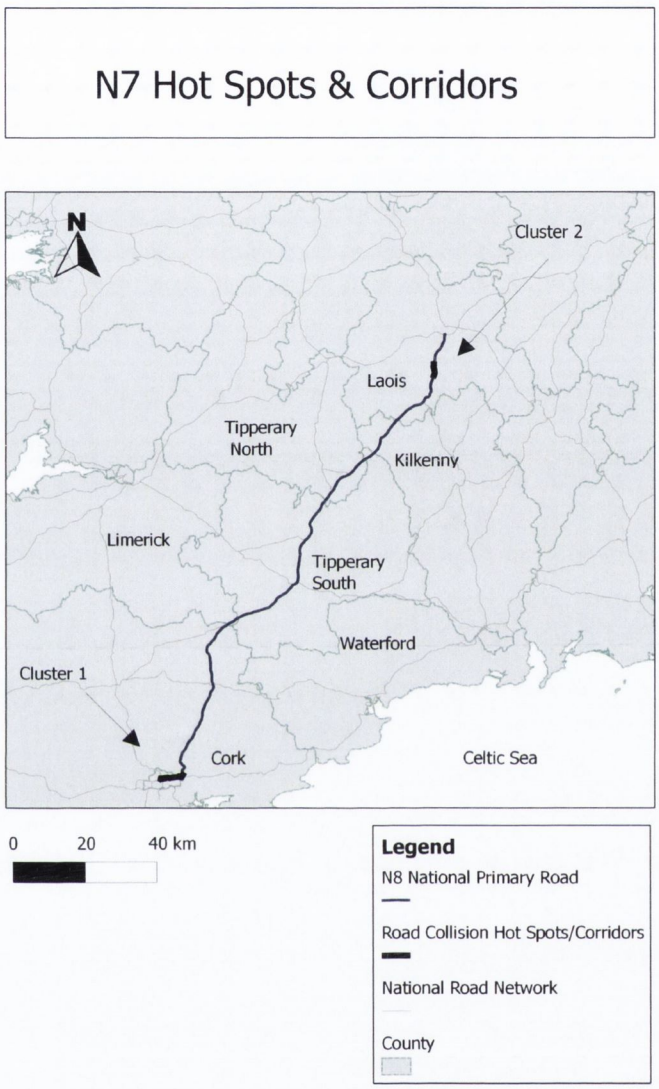


Figure 8: N8 Collision Hot Spots/Corridors

Table 17: N8 Road Collision Hot Spots/Corridors

Description	Cluster 1	Cluster 2
Number of Collisions	38	25
Collision Type		
Pedestrian	9	3
Single Vehicle	9	5
Head-on	1	5
Angle	4	1
Rear-end	8	7
Unknown	7	4
Light		
Hours of daylight	0	1
Hours of darkness	38	23
Unknown	0	1
Day		
Weekday	26	17
Weekend	9	7
Bank holiday weekend	3	1
Road Surface		
Dry	21	12
Wet	14	10
Other/Unknown	3	3
Junction		
Yes	14	6
No	24	19
Speed Limit		
$\leq$ 60 km/h	32	6
80km/h	2	4
100km/h	4	15
120km/h	0	0
Injuries		
Fatal	2	2
Serious	3	10
Minor	38	30
Not Injured/Unknown	0	2

The N9 is the primary road to Waterford City, Co. Waterford, which begins at the M7/M9 interchange at junction 11. New sections of motorway opened in 2010 from Kilcullen, Co. Kildare to Carlow. One hundred and ninety three road traffic collisions were recorded on the N9/M9 road from 2005-2009. The scan statistic was run on 110 road traffic collisions as collisions with geographical coordinates located more than 100m from the N8 road were excluded from the analysis. One cluster was identified, and Table 18 gives detailed description of this cluster. A geographical representation of the clusters can be seen in the map: N9 hot spots and corridors.

- **Cluster 1**
  - Location: Jerpoint Abbey, Mill St, Co. Kilkenny - R705/N9 intersection Co. Carlow
  - Number of collisions: 95
  - Length: 35km

Approximately 48.4% (13/38) of the collisions recorded in cluster 1 were multi-vehicle collisions. Seventy six percent (72/95) collisions recorded occurred during the hours of darkness and 61.1% (58/95) occurred on a weekday. Approximately 51.6% (49/95) occurred on a dry road surface, 17.9% (17/95) occurred at a junction and 88.4% (84/95) collisions recorded occurred on sections of road with speed limits 100km/h. One hundred and thirty nine of injuries sustained were minor injuries, fourteen serious injuries and eight fatalities were recorded in this cluster.

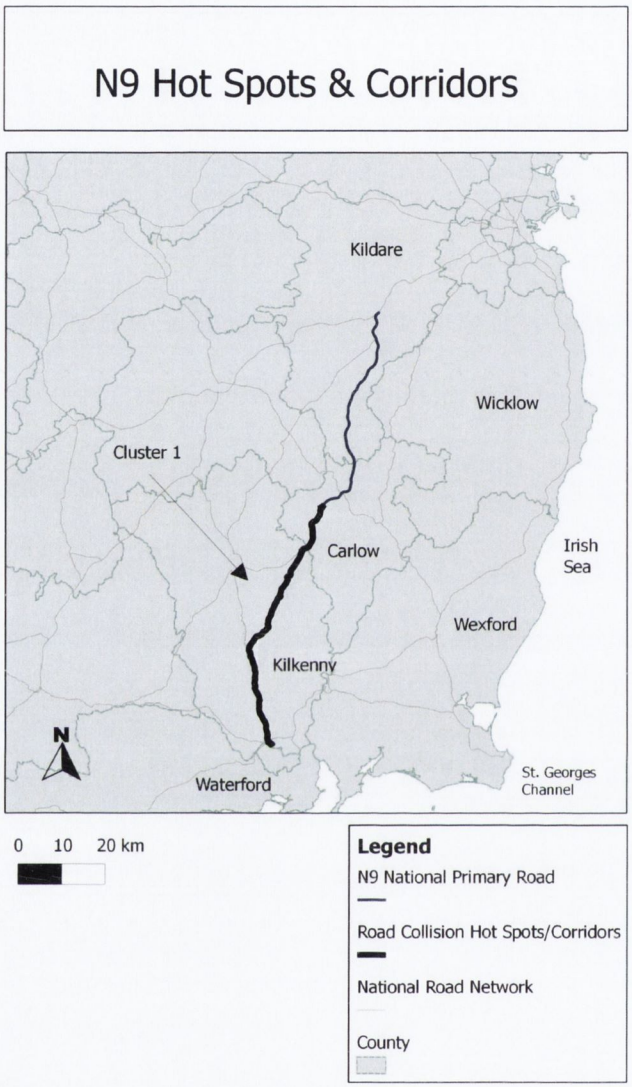


Figure 9: N9 Collision Hot Spots/Corridors

Table 18: N9 Road Collision Hot Spots/Corridors

Description	Cluster 1
Number of Collisions	95
Collision Type	
Pedestrian	6
Single Vehicle	29
Head-on	25
Angle	6
Rear-end	15
Unknown	14
Light	
Hours of daylight	21
Hours of darkness	72
Unknown	2
Day	
Weekday	58
Weekend	34
Bank holiday weekend	3
Road Surface	
Dry	49
Wet	40
Other/Unknown	6
Junction	
Yes	17
No	78
Speed Limit	
$\leq$ 60 km/h	9
80km/h	2
100km/h	84
120km/h	0
Injuries	
Fatal	8
Serious	14
Minor	139
Not Injured/Unknown	8

N10 national primary road connects Kilkenny to the main N9 Dublin - Waterford route. Sixty road traffic collisions were recorded on the N10 road from 2005-2009. The scan statistic was run on 56 road traffic collisions as collisions with geographical coordinates located more than 100m from the N10 road were excluded from the analysis. Two clusters were identified, and Table 19 gives detailed description of each cluster. A geographical representation of the clusters can be seen in the map: N10 hot spots and corridors.

- **Cluster 1**
  - Location: South of Flood Hall, Co. Kilkenny - Floodhall, Co. Kilkenny
  - Number of collisions: 6
  - Length: 81m

All of the collisions recorded in cluster 1 were single-vehicle collisions. Sixty seven percent (4/7) collisions recorded occurred during the hours of darkness and 71.4% (5/7) occurred on a weekday. Approximately 14.3% (1/7) occurred on a dry road surface, zero occurred at a junction and all collisions recorded occurred on sections of road with speed limits 100km/h. Seven of injuries sustained were minor injuries, zero serious injuries and zero fatalities were recorded in this cluster.

- **Cluster 2**
  - Location: Ring Road Kilkenny, Co. Kilkenny
  - Number of collisions: 5
  - Length: 227m

Approximately 60% (3/5) of the collisions recorded in cluster 2 were multi-vehicle collisions. All collisions recorded occurred during the hours of darkness and 60% (3/5) occurred on a weekday. Approximately 60% (3/5) occurred on a dry road surface, zero occurred at a junction and all collisions recorded occurred on sections of road with speed limits 100km/h. Six of injuries sustained were minor injuries, one serious injury and zero fatalities were recorded in this cluster.

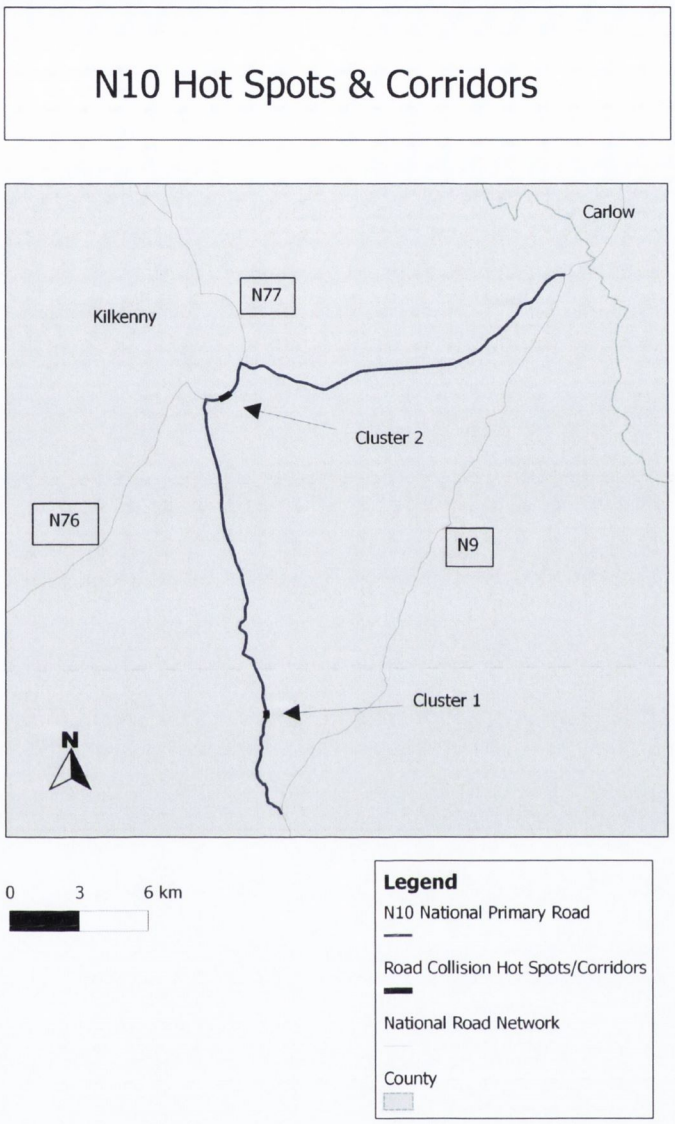


Figure 10: N10 Collision Hot Spots/Corridors

Table 19: N10 Road Collision Hot Spots/Corridors

Description	Cluster 1	Cluster 2
Number of Collisions	6	5
Collision Type		
Pedestrian	0	0
Single Vehicle	6	1
Head-on	0	0
Angle	0	0
Rear-end	0	3
Unknown	0	1
Light		
Hours of daylight	2	0
Hours of darkness	4	5
Unknown 0	0	
Day		
Weekday	5	3
Weekend	1	2
Bank holiday weekend	0	0
Road Surface		
Dry	1	3
Wet	5	1
Other/Unknown	0	1
Junction		
Yes	0	0
No	6	5
Speed Limit		
$\leq$ 60 km/h	0	0
80km/h	0	0
100km/h	6	5
120km/h	0	0
Injuries		
Fatal	0	0
Serious	0	1
Minor	7	6
Not Injured/Unknown	0	0

The N11 national primary road connects Dublin City to Wexford. Four hundred and eight road traffic collisions were recorded on the N11 road from 2005-2009. The scan statistic was run on 372 road traffic collisions as collisions with geographical coordinates located more than 100m from the N11 road were excluded from the analysis. Three clusters were identified, and Table 20 gives detailed description of each cluster. A geographical representation of the clusters can be seen in the map: N11 hot spots and corridors.

- **Cluster 1**
  - Location: Dublin Road, Dublin 18 (near Seaview Wood roundabout) - Leinster Street/Kildare Street intersection, Dublin City
  - Number of collisions: 147
  - Length: 15.1km

Approximately 50.3% (74/147) of the collisions recorded in cluster 1 were multi-vehicle collisions. Ninety seven percent (143/147) collisions recorded occurred during the hours of darkness and 75.5% (141/147) occurred on a weekday. Approximately 68.7% (101/147) occurred on a dry road surface, 47% (69/147) occurred at a junction and 75.5% (111/147) collisions recorded occurred on sections of road with speed limits 60km/h and below. One hundred sixty two of injuries sustained were minor injuries, thirteen serious injuries and one fatality were recorded in this cluster.

- **Cluster 2**
  - Location: Jack White Cross Roads, Co. Wicklow
  - Number of collisions: 5
  - Length: 22m

Approximately 60% (3/5) of the collisions recorded in cluster 2 were multi-vehicle collisions. All collisions recorded occurred during the hours of darkness and 60% (3/5) occurred on a weekday. Approximately 80% (4/5) occurred on a dry road surface, zero occurred at a junction and all collisions recorded occurred on sections of road with speed limits 100km/h. Nine of injuries sustained were minor injuries, zero serious injuries and zero fatalities were recorded in this cluster.

- **Cluster 3**
  - Location:Barndarrig, Co. Wicklow - South of Ballinameesda Upper, Co. Wicklow

- Number of collisions: 30
- Length: 3.1km

Approximately 40% (12/30) of the collisions recorded in cluster 3 were multi-vehicle collisions and 36.7% (11/30) are single vehicle collisions. Eighty percent (24/30) collisions recorded occurred during the hours of darkness and 66.7% (20/30) occurred on a weekday. Approximately 66.7% (20/30) occurred on a dry road surface, 6.7% (2/30) occurred at a junction and 50% (15/30) of collisions recorded occurred on sections of road with speed limits 100km/h. Thirty eight injuries sustained were minor injuries, twelve serious injuries and three fatalities were recorded in this cluster.

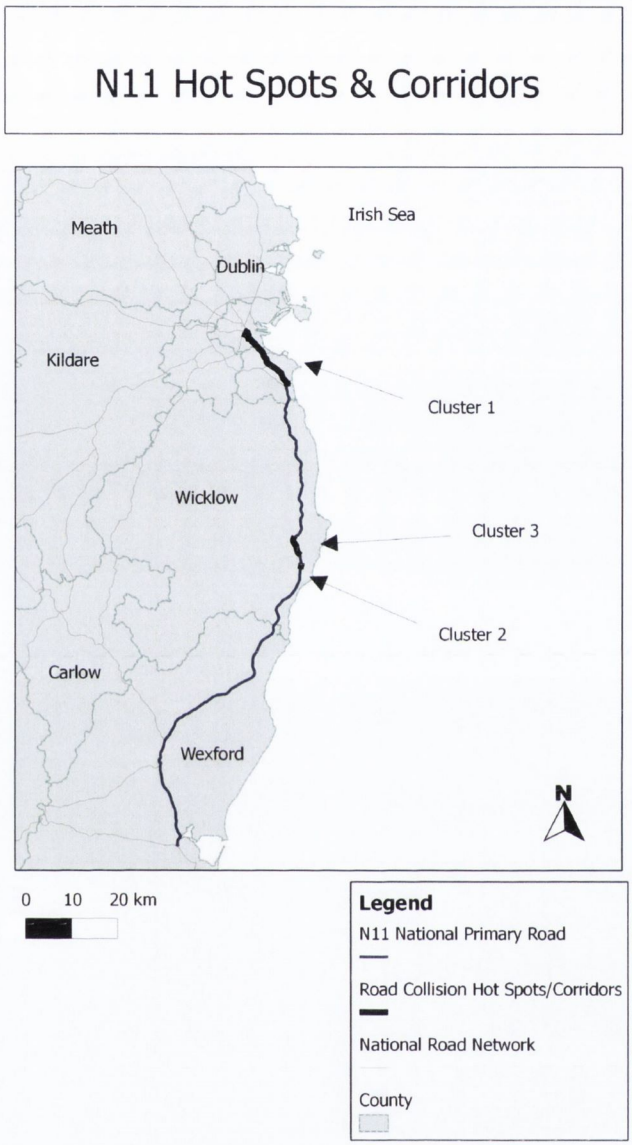


Figure 11: N11 Collision Hot Spots/Corridors

Table 20: N11 Road Collision Hot Spots/Corridors

Description	Cluster 1	Cluster 2	Cluster 3
Number of Collisions	147	5	30
Collision Type			
Pedestrian	31	0	0
Single Vehicle	9	0	11
Head-on	9	2	5
Angle	34	1	2
Rear-end	31	0	5
Unknown	33	2	7
Light			
Hours of daylight	1	0	6
Hours of darkness	143	5	24
Unknown	3	0	
Day			
Weekday	111	3	20
Weekend	35	2	9
Bank holiday weekend	1	0	1
Road Surface			
Dry	101	4	17
Wet	39	1	10
Other/Unknown	7	0	3
Junction			
Yes	69	0	2
No	78	5	28
Speed Limit			
$\leq$ 60 km/h	111	0	0
80km/h	11	0	15
100km/h	25	5	15
120km/h	0	0	0
Injuries			
Fatal	1	0	3
Serious	13	0	12
Minor	162	9	38
Not Injured/Unknown	9	0	5

The N13 national primary road connects Stranolar Co. Donegal to the Northern Ireland border near Derry. Sixty seven road traffic collisions were recorded on the N13 road from 2005-2009. The scan statistic was run on 64 road traffic collisions as collisions with geographical coordinates located more than 100m from the N13 road were excluded from the analysis. One cluster was identified, and Table 21 gives detailed description of this cluster. A geographical representation of the clusters can be seen in the map: N13 hot spots and corridors.

- **Cluster 1**
  - Location: South West of Moyle, Co. Donegal - North East of Moyle, Co. Donegal
  - Number of collisions: 9
  - Length: 732m

Approximately 44.4% (4/9) of the collisions recorded in cluster 1 were multi-vehicle collisions. Seventy eight percent (7/9) collisions recorded occurred during the hours of darkness and 33.3% (3/8) occurred on a weekday. Approximately 11.1% (1/9) occurred on a dry road surface, 33.3% (3/9) occurred at a junction and all collisions recorded occurred on sections of road with speed limits 100km/h. Sixteen injuries sustained were minor injuries, three serious injuries and four fatalities were recorded in this cluster.

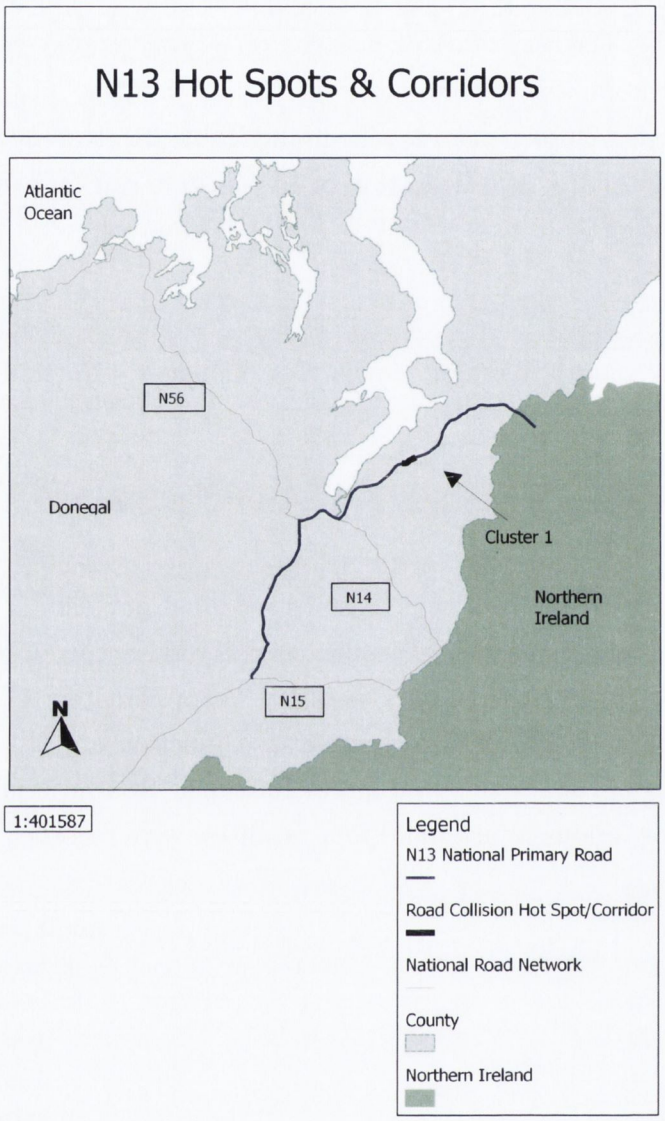


Figure 12: N13 Collision Hot Spots/Corridors

Table 21: N13 Road Collision Hot Spots/Corridors

Description	Cluster 1
Number of Collisions	9
Collision Type	
Pedestrian	1
Single Vehicle	2
Head-on	2
Angle	1
Rear-end	1
Unknown	2
Light	
Hours of daylight	2
Hours of darkness	7
Unknown	0
Day	
Weekday	3
Weekend	6
Bank holiday weekend	0
Road Surface	
Dry	1
Wet	7
Other/Unknown	1
Junction	
Yes	3
No	6
Speed Limit	
$\leq$ 60 km/h	0
80km/h	0
100km/h	9
120km/h	0
Injuries	
Fatal	4
Serious	3
Minor	16
Not Injured/Unknown	0

The N15 national primary road connects Sligo town Co. Sligo to Lifford Co. Donegal. One hundred and sixty one road traffic collisions were recorded on the N15 road from 2005-2009. The scan statistic was run on 149 road traffic collisions as collisions with geographical coordinates located more than 100m from the N15 road were excluded from the analysis. Two clusters were identified, and Table 22 gives detailed description of each cluster. A geographical representation of the clusters can be seen in the map: N15 hot spots and corridors.

- **Cluster 1**
  - Location: Bundoran Road, Sligo, Co. Sligo
  - Number of collisions: 5
  - Length: 75m

Approximately 60% (3/5) of the collisions recorded in cluster 1 were multi-vehicle collisions. Eighty percent (4/5) collisions recorded occurred during the hours of darkness and 40% (2/5) occurred on a weekday. Approximately 40% (2/5) occurred on a dry road surface, 60% (3/5) occurred at a junction and 80% (4/5) of collisions recorded occurred on sections of road with speed limits 60km/h and below. Twelve injuries sustained were minor injuries, zero serious injuries and zero fatalities were recorded in this cluster.

- **Cluster 2**
  - Location: Donegal Road/Pettigoe road (R332) intersection
  - Number of collisions: 5
  - Length: 27m

Approximately 40% (2/5) of the collisions recorded in cluster 2 were multi-vehicle collisions. All collisions recorded occurred during the hours of darkness and 60% (3/5) occurred on a weekday. All collisions recorded occurred on a dry road surface and on sections of road with speed limits 100km/h. Approximately 80% (4/5) occurred at a junction Three injuries sustained were minor injuries, three serious injuries and zero fatalities were recorded in this cluster.

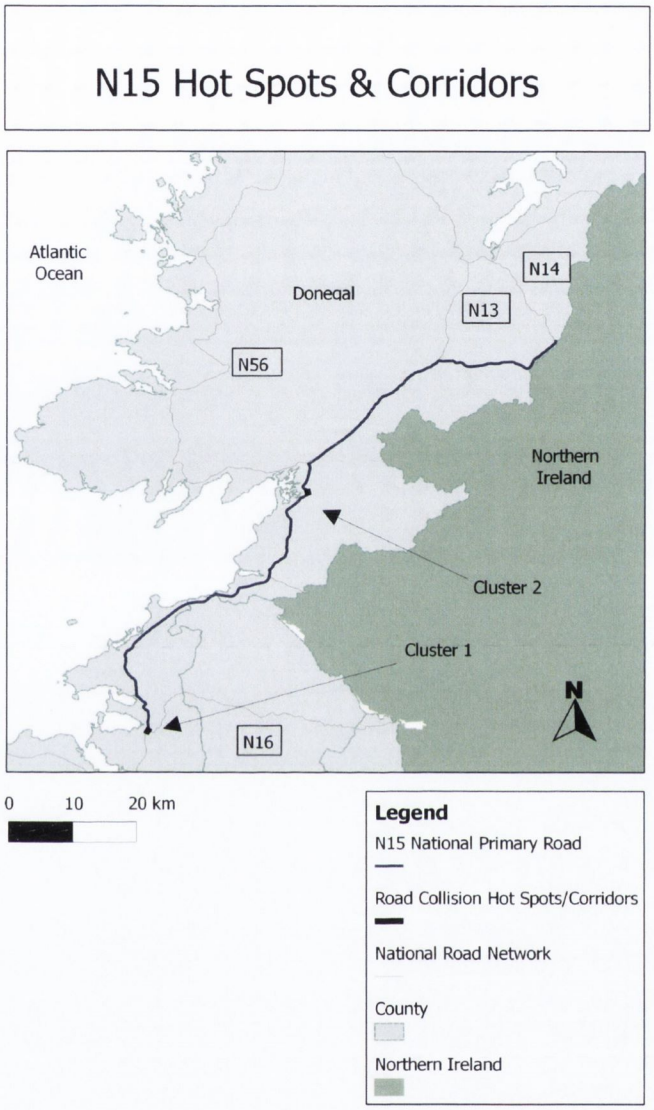


Figure 13: N15 Collision Hot Spots/Corridors

Table 22: N15 Road Collision Hot Spots/Corridors

Description	Cluster 1	Cluster 2
Number of Collisions	5	5
Collision Type		
Pedestrian	0	1
Single Vehicle	1	0
Head-on	0	0
Angle	1	2
Rear-end	2	0
Unknown	1	2
Light		
Hours of daylight	1	0
Hours of darkness	4	5
Unknown	0	0
Day		
Weekday	2	3
Weekend	3	2
Bank holiday weekend	0	0
Road Surface		
Dry	2	5
Wet	3	0
Other/Unknown	0	0
Junction		
Yes	3	4
No	2	1
Speed Limit		
$\leq$ 60 km/h	4	0
80km/h	0	0
100km/h	1	5
120km/h	0	0
Injuries		
Fatal	0	0
Serious	0	3
Minor	12	3
Not Injured/Unknown	0	0

The N16 national primary road connects Sligo town Co. Sligo to Blacklion, Co. Cavan at the Northern Ireland border (Fermanagh). Thirty nine road traffic collisions were recorded on the N16 road from 2005-2009. The scan statistic was run on 39 road traffic collisions as there were no collisions with geographical coordinates located more than 100m from the N16 road were excluded from the analysis. One cluster was identified, and Table 23 gives detailed description of this cluster. A geographical representation of the clusters can be seen in the map: N16 hot spots and corridors.

- **Cluster 1**
  - Location: Newline, Manorhamilton, Co. Leitrim - East of Tomrud, Co. Leitrim
  - Number of collisions: 20
  - Length: 7.7km

Approximately 50% (10/20) of the collisions recorded in cluster 1 were multi-vehicle collisions. Eighty percent (16/20) collisions recorded occurred during the hours of darkness and 55% (11/20) occurred on a weekday. Approximately 65% (13/20) occurred on a dry road surface, 10% (2/20) occurred at a junction and 75% (15/20) of collisions recorded occurred on sections of road with speed limits 100km/h. Nineteen injuries sustained were minor injuries, two serious injuries and three fatalities were recorded in this cluster.

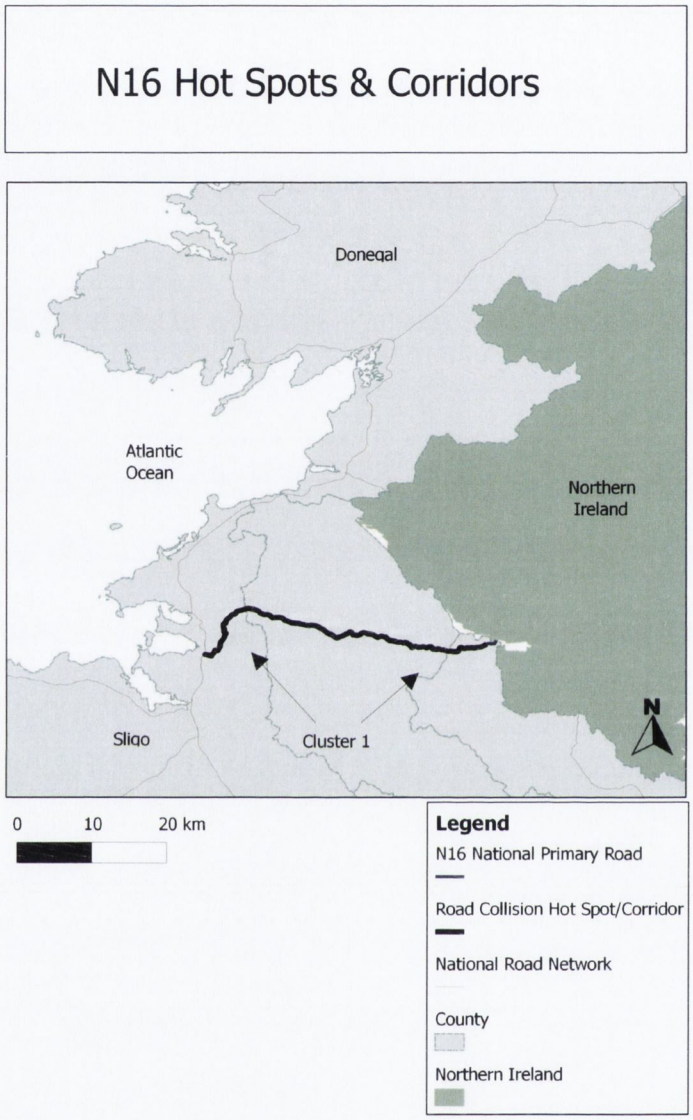


Figure 14: N16 Collision Hot Spots/Corridors

Table 23: N16 Road Collision Hot Spots/Corridors

Description	Cluster 1
Number of Collisions	20
Collision Type	
Pedestrian	3
Single Vehicle	5
Head-on	1
Angle	4
Rear-end	5
Unknown	2
Light	
Hours of daylight	4
Hours of darkness	16
Unknown	0
Day	
Weekday	11
Weekend	8
Bank holiday weekend	1
Road Surface	
Dry	13
Wet	6
Other/Unknown	1
Junction	
Yes	2
No	18
Speed Limit	
$\leq$ 60 km/h	4
80km/h	1
100km/h	15
120km/h	0
Injuries	
Fatal	3
Serious	2
Minor	19
Not Injured/Unknown	0

The N17 national primary road connects Galway City Co. Galway to the N4 near Collooney, Co. Sligo. One hundred and ninety three road traffic collisions were recorded on the N17 road from 2005-2009. The scan statistic was run on 187 road traffic collisions as collisions with geographical coordinates located more than 100m from the N17 road were excluded from the analysis. Two clusters were identified, and Table 24 gives detailed description of each cluster. A geographical representation of the clusters can be seen in the map: N17 hot spots and corridors.

- **Cluster 1**
  - Location: N17/R331 (Ballydine Road) intersection, Co. Mayo
  - Number of collisions: 8
  - Length: 190m

Approximately 50% (4/8) of the collisions recorded in cluster 1 were multi-vehicle collisions. Twenty five percent (2/8) collisions recorded occurred during the hours of darkness and 50% (4/8) occurred on a weekday. Approximately 37.5% (3/8) occurred on a dry road surface, 37.5% (3/5) occurred at a junction and all collisions recorded occurred on sections of road with speed limits 100km/h. Fifteen injuries sustained were minor injuries, two serious injuries and zero fatalities were recorded in this cluster.

- **Cluster 2**
  - Location: N17/N63 intersection, Co. Galway - South west of Laghtgeorge, Co. Galway
  - Number of collisions: 12
  - Length: 92m

Approximately 50% (6/12) of the collisions recorded in cluster 2 were multi-vehicle collisions. Ninety two percent (11/12) collisions recorded occurred during the hours of darkness and 83.3% (10/12) occurred on a weekday. Approximately 83.3% (10/12) occurred on a dry road surface, 33.3% (4/12) occurred at a junction and 83.3% (10/12) collisions recorded occurred on sections of road with speed limits 100km/h. Fourteen injuries sustained were minor injuries, two serious injuries and two fatalities were recorded in this cluster.

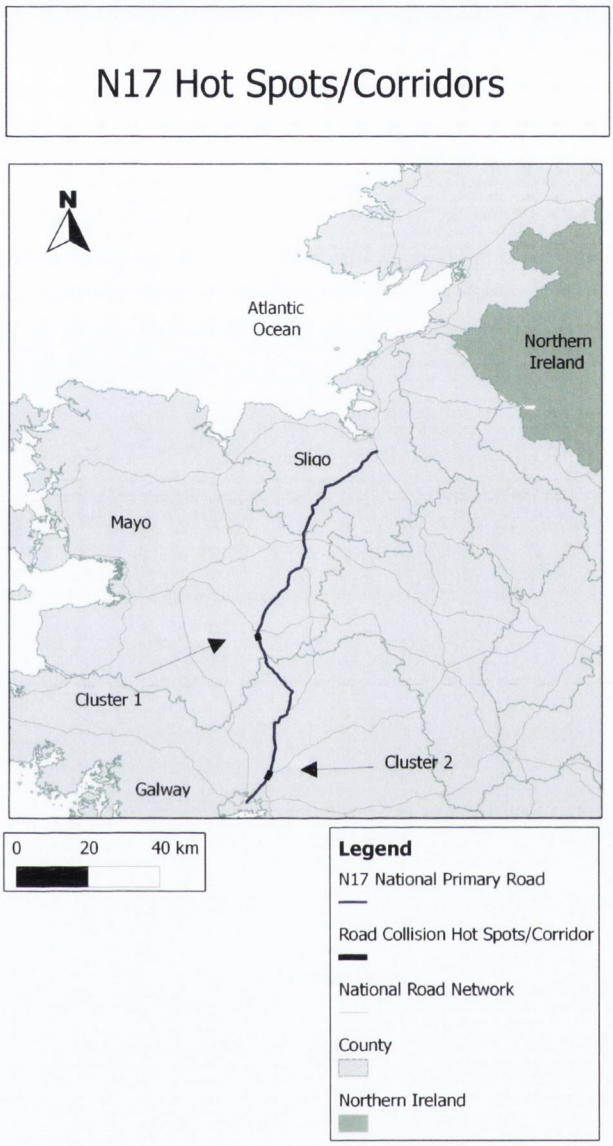


Figure 15: N17 Collision Hot Spots/Corridors

Table 24: N17 Road Collision Hot Spots/Corridors

Description	Cluster 1	Cluster 2
Number of Collisions	8	12
Collision Type		
Pedestrian	0	1
Single Vehicle	1	1
Head-on	1	2
Angle	3	3
Rear-end	1	1
Unknown	2	4
Light		
Hours of daylight	4	0
Hours of darkness	2	11
Unknown	2	1
Day		
Weekday	4	10
Weekend	4	2
Bank holiday weekend	0	0
Road Surface		
Dry	3	10
Wet	2	2
Other/Unknown	3	0
Junction		
Yes	3	4
No	5	8
Speed Limit		
$\leq$ 60 km/h	0	0
80km/h	0	2
100km/h	8	10
120km/h	0	0
Injuries		
Fatal	0	2
Serious	2	2
Minor	15	14
Not Injured/Unknown	0	6

The N18 national primary road connects Limerick City Co. Limerick to the Galway City, Co. Galway. One hundred and seventy four road traffic collisions were recorded on the N18 road from 2005-2009. The scan statistic was run on 160 road traffic collisions as collisions with geographical coordinates located more than 100m from the N18 road were excluded from the analysis. One cluster was identified, and Table 25 gives detailed description of this cluster. A geographical representation of the clusters can be seen in the map: N18 hot spots and corridors.

- **Cluster 1**
  - Location: Coonagh roundabout, Limerick, Co. Limerick
  - Number of collisions: 6
  - Length: 92m

Approximately 66.7% (4/6) of the collisions recorded in cluster 1 were multi-vehicle collisions. All collisions recorded occurred during the hours of darkness and occurred on a weekday. Approximately 33.3% (2/6) occurred on a dry road surface, 83.3% (5/6) occurred at a junction and occurred on sections of road with speed limits 60km/h or less. Seven injuries sustained were minor injuries, zero serious injuries and zero fatalities were recorded in this cluster.

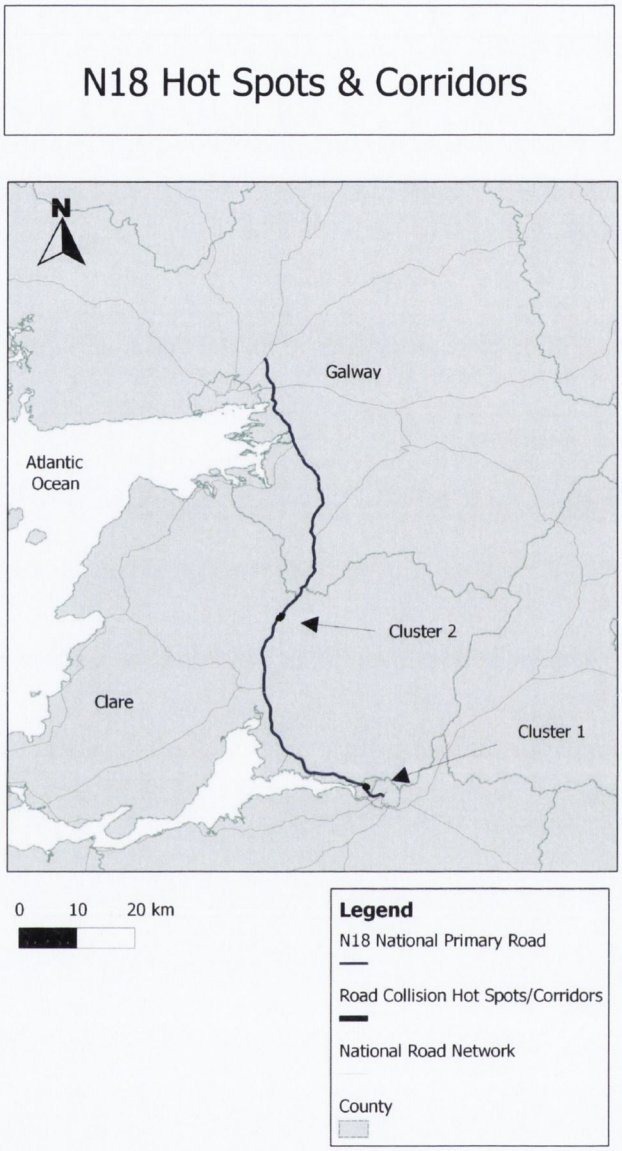


Figure 16: N18 Collision Hot Spots/Corridors

Table 25: N18 Road Collision Hot Spots/Corridors

Description	Cluster 1
Number of Collisions	6
Collision Type	
Pedestrian	0
Single Vehicle	1
Head-on	0
Angle	1
Rear-end	3
Unknown	1
Light	
Hours of daylight	0
Hours of darkness	6
Unknown	0
Day	
Weekday	6
Weekend	0
Bank holiday weekend	0
Road Surface	
Dry	2
Wet	4
Other/Unknown	0
Junction	
Yes	5
No	1
Speed Limit	
$\leq$ 60 km/h	5
80km/h	0
100km/h	1
120km/h	0
Injuries	
Fatal	0
Serious	0
Minor	7
Not Injured/Unknown	1

The N20 national primary road connects Cork City, Co. Cork to the N21/M20 outside Limerick City, Co. Limerick. Two hundred and fifteen road traffic collisions were recorded on the N20 road from 2005-2009. The scan statistic was run on 199 road traffic collisions as collisions with geographical coordinates located more than 100m from the N20 road were excluded from the analysis. Three clusters were identified, and Table 26 gives detailed description of each cluster. A geographical representation of the clusters can be seen in the map: N20 hot spots and corridors.

- **Cluster 1**
  - Location: N20/R518 intersection, Limerick, Co. Limerick
  - Number of collisions: 5
  - Length: 16m

All of the collisions recorded in cluster 1 were multi-vehicle collisions. Sixty percent of collisions recorded occurred during the hours of darkness and all occurred on a weekday. Approximately 40% (2/5) occurred on a dry road surface, 80% (4/5) occurred at a junction and occurred on sections of road with speed limits 100km/h. Seven injuries sustained were minor injuries, zero serious injuries and one fatality were recorded in this cluster.

- **Cluster 2**
  - Location: North ring road, Cork, Co. Cork - Commons road, Cork, Co. Cork
  - Number of collisions: 19
  - Length: 1.5km

Approximately 84.2% (16/19) of the collisions recorded in cluster 2 were multi-vehicle collisions. All of collisions recorded occurred during the hours of darkness and 84.2% (16/19) occurred on a weekday. Approximately 68.4% (13/19) occurred on a dry road surface, 26.3% (5/14) occurred at a junction and 94.7%(18/19) occurred on sections of road with speed limits 60km/h or less. Twenty three injuries sustained were minor injuries, two serious injuries and zero fatalities were recorded in this cluster.

- **Cluster 3**
  - Location: Main street Charleville, Co. Cork - Limerick road Charleville, Co. Cork
  - Number of collisions: 7

– Length: 208m

Approximately 42.9% (3/7) of the collisions recorded in cluster 3 were multi-vehicle collisions and 42.9% (3/7) were pedestrian involved collisions. All of collisions recorded occurred during the hours of darkness and 71.4% (5/7) occurred on a weekday. Approximately 57.1% (4/7) occurred on a dry road surface, 42.9% (3/7) occurred at a junction and all recorded collisions occurred on sections of road with speed limits 60km/h or less. Nine injuries sustained were minor injuries, zero serious injuries and zero fatalities were recorded in this cluster.

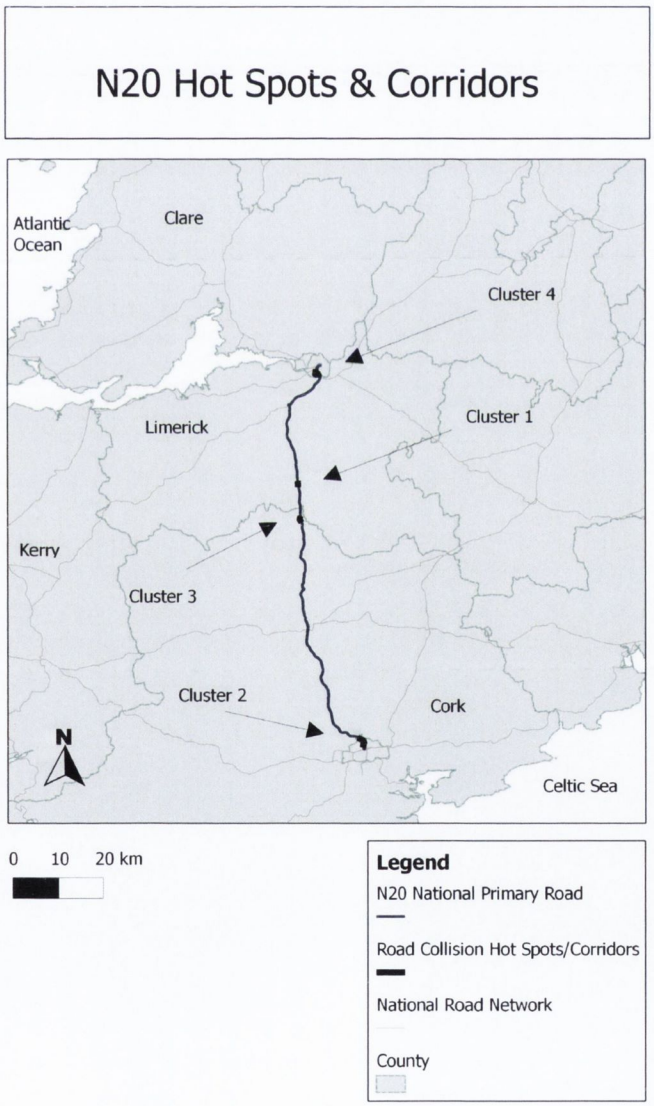


Figure 17: N20 Collision Hot Spots/Corridors

Table 26: N20 Road Collision Hot Spots/Corridors

Description	Cluster 1	Cluster 2	Cluster 3
Number of Collisions	5	19	7
Collision Type			
Pedestrian	0	1	3
Single Vehicle	0	0	0
Head-on	1	3	0
Angle	1	5	2
Rear-end	2	8	1
Unknown	1	2	1
Light			
Hours of daylight	1	0	0
Hours of darkness	3	18	7
Unknown	1	0	0
Day			
Weekday	5	16	5
Weekend	0	3	2
Bank holiday weekend	0	0	0
Road Surface			
Dry	2	13	4
Wet	2	4	3
Other/Unknown	1	2	0
Junction			
Yes	4	5	3
No	1	14	4
Speed Limit			
$\leq$ 60 km/h	0	18	7
80km/h	1	0	0
100km/h	4	1	0
120km/h	0	0	0
Injuries			
Fatal	1	0	0
Serious	0	2	0
Minor	7	23	9
Not Injured/Unknown	1	0	0

The N21 national primary road connects Tralee, Co. Kerry to the N20/M20 outside Limerick City, Co. Limerick. One hundred and forty seven road traffic collisions were recorded on the N20 road from 2005-2009. The scan statistic was run on 143 road traffic collisions as collisions with geographical coordinates located more than 100m from the N21 road were excluded from the analysis. One cluster was identified, and Table 27 gives detailed description of this cluster. A geographical representation of the clusters can be seen in the map: N21 hot spots and corridors.

- **Cluster 1**
  - Location: Convent road, Abbeyfeale, Co. Limerick - Bridge street Abbeyfeale, Co. Limerick
  - Number of collisions: 11
  - Length: 728m

Approximately 54.5% (6/11) of the collisions recorded in cluster 1 were pedestrian involved collisions. All collisions recorded occurred during the hours of darkness and 63.6%(7/11) occurred on a weekday. Approximately 36.4% (4/11) occurred on a dry road surface, 9% (1/11) occurred at a junction and all occurred on sections of road with speed limits 60km/h or less. Eight injuries sustained were minor injuries, six serious injuries and zero fatalities were recorded in this cluster.

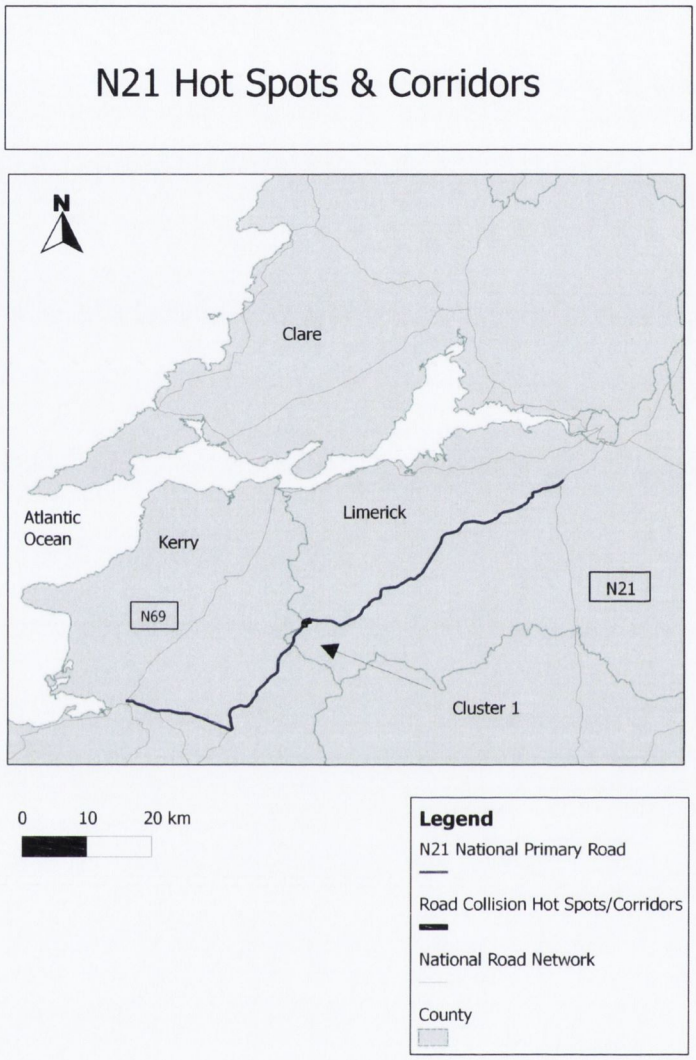


Figure 18: N21 Collision Hot Spots/Corridors

Table 27: N21 Road Collision Hot Spots/Corridors

Description	Cluster 1
Number of Collisions	11
Collision Type	
Pedestrian	6
Single Vehicle	0
Head-on	1
Angle	0
Rear-end	2
Unknown	2
Light	
Hours of daylight	0
Hours of darkness	11
Unknown	0
Day	
Weekday	7
Weekend	4
Bank holiday weekend	0
Road Surface	
Dry	4
Wet	7
Other/Unknown	0
Junction	
Yes	1
No	10
Speed Limit	
$\leq$ 60 km/h	11
80km/h	0
100km/h	0
120km/h	0
Injuries	
Fatal	0
Serious	6
Minor	8
Not Injured/Unknown	0

The N22 national primary road connects Cork City, Co. Cork to the N21 outside Tralee, Co. Kerry. Two hundred and thirty six road traffic collisions were recorded on the N22 road from 2005-2009. The scan statistic was run on 223 road traffic collisions as collisions with geographical coordinates located more than 100m from the N22 road were excluded from the analysis. Three clusters were identified, and Table 28 gives detailed description of each cluster. A geographical representation of the clusters can be seen in the map: N22 hot spots and corridors.

- **Cluster 1**
  - Location: N72,N22 Intersection, Lissivigeen, Co. Kerry - Lissivigeen road, Co. Kerry
  - Number of collisions: 14
  - Length: 689m

Approximately 85.7% (12/14) of the collisions recorded in cluster 1 were multi-vehicle collisions. Ninety three percent of collisions recorded occurred during the hours of darkness and 64.3%(9/14) occurred on a weekday. Approximately 42.9% (6/14) occurred on a dry road surface, 71.4% (10/14) occurred at a junction and 78.6% (11/14) occurred on sections of road with speed limits 100km/h. Seventeen injuries sustained were minor injuries, zero serious injuries and zero fatalities were recorded in this cluster.

- **Cluster 2**
  - Location: St. Patrick's St. Cork, Co. Cork - N22/Washington St intersection, Cork, Co. Cork
  - Number of collisions: 14
  - Length: 689m

Approximately 69.2% (9/13) of the collisions recorded in cluster 2 were pedestrian involved collisions. All collisions recorded occurred during the hours of darkness and 69.2%(9/13) occurred on a weekday. Approximately 69.2% (9/13) occurred on a dry road surface, 53.9% (7/13) occurred at a junction and all recorded collisions occurred on sections of road with speed limits 80km/h or less. Seventeen injuries sustained were minor injuries, two serious injuries and zero fatalities were recorded in this cluster.

- **Cluster 3**
  - Location: Intersection R561, N22, Farranfore, Co. Kerry - North of N22/R561 intersection, Farranfore, Co. Kerry

- Number of collisions: 6
- Length: 123m

Approximately 66.7% (4/6) of the collisions recorded in cluster 3 were multi-vehicle collisions. All collisions recorded occurred during the hours of darkness and 83.3%(5/6) occurred on a weekday. Approximately 50% (3/6) occurred on a dry road surface, 66.7% (4/6) occurred at a junction and 83.3%(5/6) recorded collisions occurred on sections of road with speed limits 60km/h or less. Nine injuries sustained were minor injuries, zero serious injuries and one fatalities were recorded in this cluster.

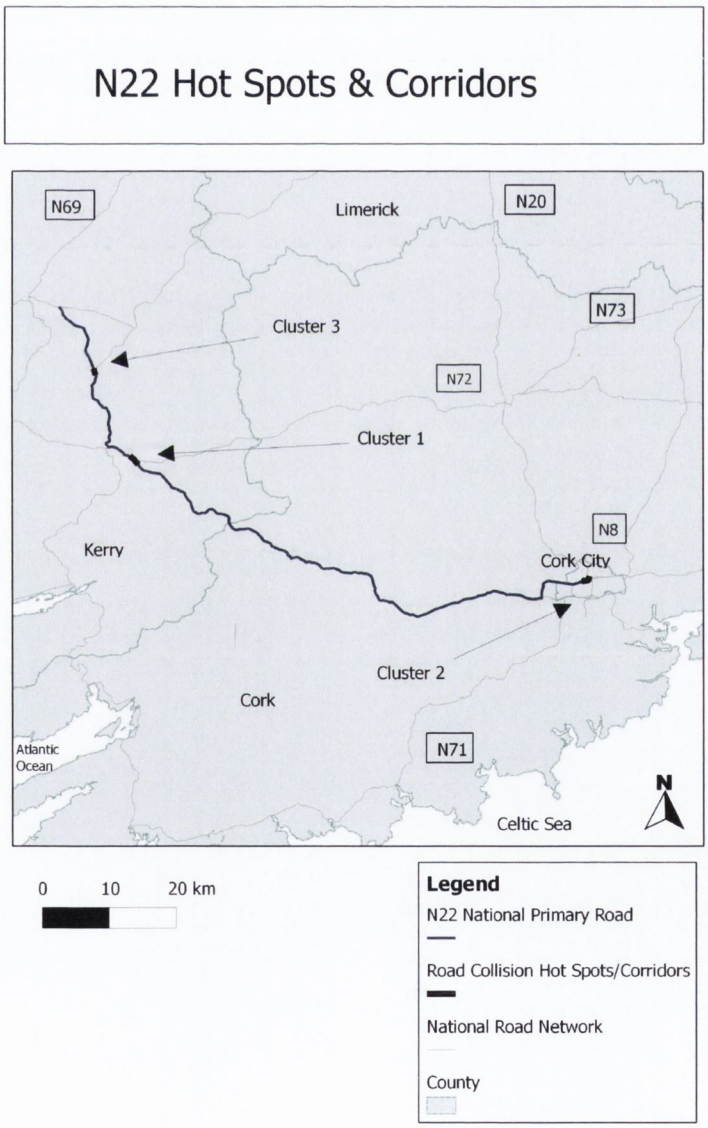


Figure 19: N22 Collision Hot Spots/Corridors

Table 28: N22 Road Collision Hot Spots/Corridors

Description	Cluster 1	Cluster 2	Cluster 3
Number of Collisions	14	13	6
Collision Type			
Pedestrian	0	9	0
Single Vehicle	0	0	1
Head-on	3	1	1
Angle	6	0	1
Rear-end	3	2	2
Unknown	2	1	1
Light			
Hours of daylight	1	0	0
Hours of darkness	13	13	6
Unknown	0	0	
Day			
Weekday	9	9	5
Weekend	2	4	0
Bank holiday weekend	3	0	1
Road Surface			
Dry	6	9	3
Wet	8	4	3
Other/Unknown	0	0	0
Junction			
Yes	10	7	4
No	4	6	2
Speed Limit			
$\leq$ 60 km/h	3	12	5
80km/h	0	1	0
100km/h	11	0	1
120km/h	0	0	0
Injuries			
Fatal	0	0	1
Serious	0	2	0
Minor	17	17	9
Not Injured/Unknown	0	2	1

The N24 national primary road connects Waterford City, Co. Waterford to Limerick City, Co. Limerick Two hundred and thirty seven road traffic collisions were recorded on the N24 road from 2005-2009. The scan statistic was run on 189 road traffic collisions as collisions with geographical coordinates located more than 100m from the N24 road were excluded from the analysis. One cluster was identified, and Table 29 gives detailed description of this cluster. A geographical representation of the clusters can be seen in the map: N24 hot spots and corridors.

- **Cluster 1**
  - Location: Haywood Road, Clonmel, Co. Tipperary - N24/R689 intersection, Clonmel, Co. Tipperary
  - Number of collisions: 12
  - Length: 1.2km

Approximately 66.7% (8/12) of the collisions recorded in cluster 1 were multi-vehicle collisions. Ninety two percent of collisions recorded occurred during the hours of darkness and 66.7%(8/12) occurred on a weekday. Approximately 58.3% (7/12) occurred on a dry road surface, 75% (9/12) occurred at a junction and 83.3% (10/12) occurred on sections of road with speed limits 60km/h or less. Sixteen injuries sustained were minor injuries, one serious injury and zero fatalities were recorded in this cluster.

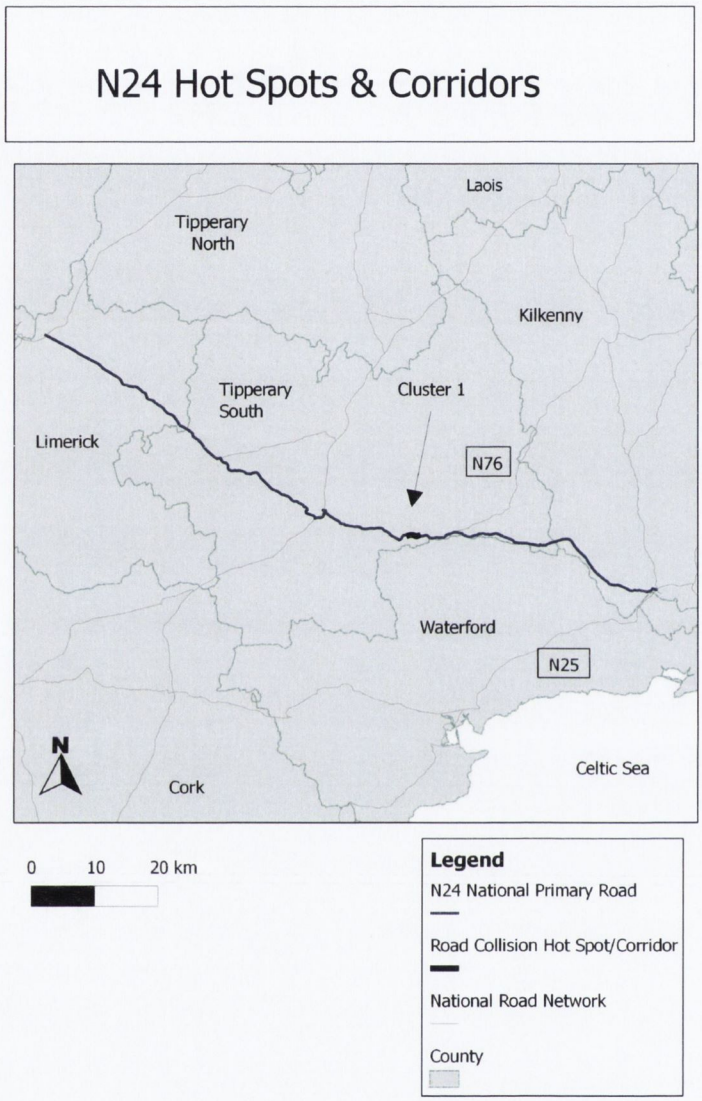


Figure 20: N24 Collision Hot Spots/Corridors

Table 29: N24 Road Collision Hot Spots/Corridors

Description	Cluster 1
Number of Collisions	12
Collision Type	
Pedestrian	1
Single Vehicle	1
Head-on	3
Angle	2
Rear-end	3
Unknown	2
Light	
Hours of daylight	1
Hours of darkness	11
Unknown	0
Day	
Weekday	8
Weekend	4
Bank holiday weekend	0
Road Surface	
Dry	7
Wet	5
Other/Unknown	0
Junction	
Yes	9
No	3
Speed Limit	
$\leq$ 60 km/h	10
80km/h	2
100km/h	0
120km/h	0
Injuries	
Fatal	0
Serious	1
Minor	16
Not Injured/Unknown	4

The N25 national primary road connects Waterford City, Co. Waterford to Cork City, Co. Cork Three hundred and ninety six road traffic collisions were recorded on the N25 road from 2005-2009. The scan statistic was run on 331 road traffic collisions as collisions with geographical coordinates located more than 100m from the N25 road were excluded from the analysis. Three clusters were identified, and Table 30 gives detailed description of each cluster. A geographical representation of the clusters can be seen in the map: N25 hot spots and corridors.

- **Cluster 1**
  - Location: Bandon Road Roundabout, Cork, Co. Cork - East of Ballyedekin, Co. Cork
  - Number of collisions: 99
  - Length: 31.7km

Approximately 57.8% (57/99) of the collisions recorded in cluster 1 were multi-vehicle collisions and 25.3% (25/99) were single vehicle collisions. Eighty six percent of collisions recorded occurred during the hours of darkness and 68.7% (68/99) occurred on a weekday. Approximately 49.5% (49/99) occurred on a dry road surface, 17.2% (17/99) occurred at a junction and 75.8% (75/99) occurred on sections of road with speed limits 100km/h. One hundred and fifteen injuries sustained were minor injuries, six serious injuries and three fatalities were recorded in this cluster.

- **Cluster 2**
  - Location: South West of N30/N25 intersection, Co. Wexford - N30/N25 intersection, New Ross, Co. Wexford
  - Number of collisions: 6
  - Length: 51m

All of the collisions recorded in cluster 2 were multi-vehicle collisions and all occurred during the hours of darkness and 68.7% (68/99) occurred on a weekday. Approximately 50% (3/6) occurred on a dry road surface, 83.3% (5/6) occurred at a junction and all occurred on sections of road with speed limits 100km/h. Nine injuries sustained were minor injuries, zero serious injuries and zero fatalities were recorded in this cluster.

- **Cluster 3**
  - Location: West of Larkins Cross, Co. Wexford - Larkins Cross Co. Wexford

- Number of collisions: 6
- Length: 63m

Approximately 66.7% (4/6) of the collisions recorded in cluster 3 were multi-vehicle collisions and all occurred during the hours of darkness and 50% (3/6) occurred on a weekday. Approximately 66.7% (4/6) occurred on a dry road surface, 83.3% (5/6) occurred at a junction and all occurred on sections of road with speed limits 100km/h. Five injuries sustained were minor injuries, three serious injuries and three fatalities were recorded in this cluster.

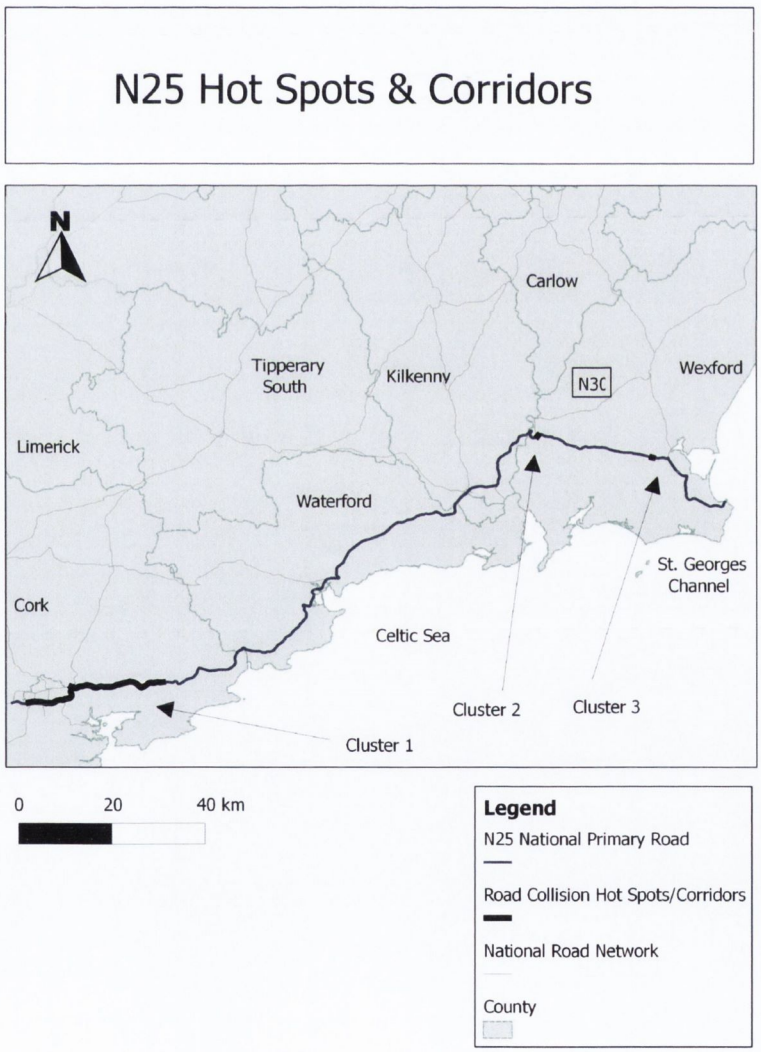


Figure 21: N25 Collision Hot Spots/Corridors

Table 30: N25 Road Collision Hot Spots/Corridors

Description	Cluster 1	Cluster 2	Cluster 3
Number of Collisions	99	6	6
Collision Type			
Pedestrian	2	0	0
Single Vehicle	25	0	0
Head-on	6	5	1
Angle	14	1	3
Rear-end	37	0	1
Unknown	15	0	1
Light			
Hours of daylight	12	0	0
Hours of darkness	85	6	6
Unknown	2	0	0
Day			
Weekday	68	6	3
Weekend	31	0	2
Bank holiday weekend	0	0	1
Road Surface			
Dry	49	3	4
Wet	46	3	2
Other/Unknown	4	0	0
Junction			
Yes	17	5	5
No	82	1	1
Speed Limit			
$\leq$ 60 km/h	19	0	0
80km/h	5	0	0
100km/h	75	6	6
120km/h	0	0	0
Injuries			
Fatal	3	0	3
Serious	6	0	3
Minor	115	9	5
Not Injured/Unknown	14	0	1

The N30 national primary road connects New Ross, Co. Wexford to Enniscorthy, Co. Wexford Fifty one road traffic collisions were recorded on the N30 road from 2005-2009. The scan statistic was run on 50 road traffic collisions as collisions with geographical coordinates located more than 100m from the N30 road were excluded from the analysis. One cluster was identified, and Table 31 gives detailed description of this cluster. A geographical representation of the clusters can be seen in the map: N30 hot spots and corridors.

- **Cluster 1**
  - Location: Mill Park Road, Enniscorthy, Co. Wexford - Abbey Square roundabout, Enniscorthy, Co. Wexford
  - Number of collisions: 7
  - Length: 323m

Approximately 57.1% (4/7) of the collisions recorded in cluster 1 were single vehicle collisions and 42.9% (3/7) were pedestrian involved collisions. All collisions recorded occurred during the hours of darkness and 85.7% (6/7) occurred on a weekday. Approximately 57.1% (4/7) occurred on a dry road surface, 42.9% (3/7) occurred at a junction and 71.4% (5/7) occurred on sections of road with speed limits 60km/h or less. Seven injuries sustained were minor injuries, one serious injury and zero fatalities were recorded in this cluster.

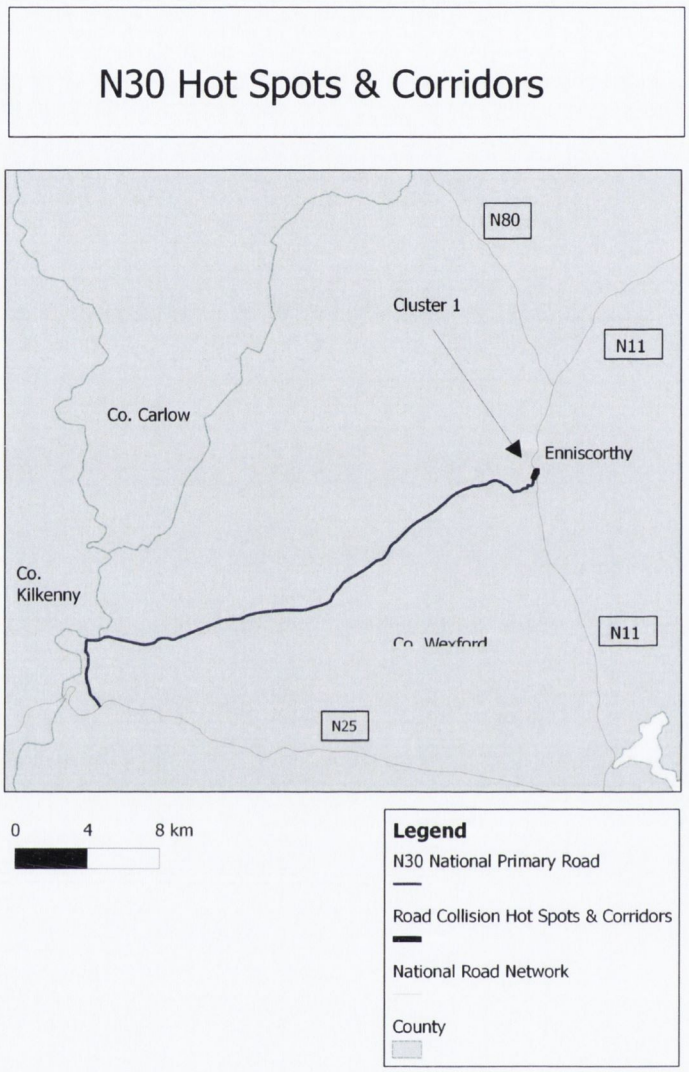


Figure 22: N30 Collision Hot Spots/Corridors

Table 31: N30 Road Collision Hot Spots/Corridors

Description	Cluster 1
Number of Collisions	7
Collision Type	
Pedestrian	3
Single Vehicle	4
Head-on	0
Angle	0
Rear-end	0
Unknown	0
Light	
Hours of daylight	0
Hours of darkness	7
Unknown	0
Day	
Weekday	6
Weekend	1
Bank holiday weekend	0
Road Surface	
Dry	4
Wet	2
Other/Unknown	1
Junction	
Yes	3
No	4
Speed Limit	
$\leq$ 60 km/h	5
80km/h	0
100km/h	2
120km/h	0
Injuries	
Fatal	0
Serious	1
Minor	7
Not Injured/Unknown	0

The N32 national primary road connects Junction 3 on the M50 to the Malahide road at Clare Hall, Co. Dublin Fifteen road traffic collisions were recorded on the N32 road from 2005-2009. The scan statistic was run on 9 road traffic collisions as collisions with geographical coordinates located more than 100m from the N32 road were excluded from the analysis. One cluster was identified, and Table 32 gives detailed description of this cluster. A geographical representation of the clusters can be seen in the map: N32 hot spots and corridors.

- **Cluster 1**
  - Location: Malahide Road, Co. Dublin
  - Number of collisions: 5
  - Length: 322m

Approximately 60% (3/5) of the collisions recorded in cluster 1 were multi-vehicle collisions and 40% (2/5) were pedestrian involved collisions. All collisions recorded occurred during the hours of darkness and occurred on a weekday. Approximately 80% (4/5) occurred on a dry road surface, 60% (3/5) occurred at a junction and 80% (4/5) occurred on sections of road with speed limits 60km/h or less. Three injuries sustained were minor injuries, two serious injuries and one fatality were recorded in this cluster.

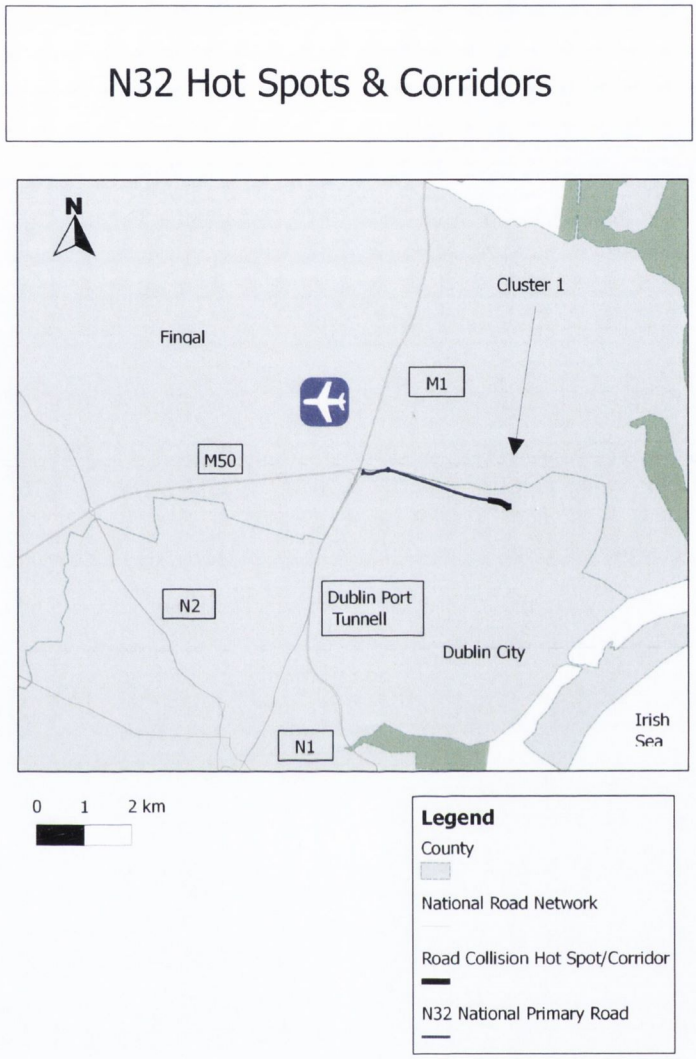


Figure 23: N32 Collision Hot Spots/Corridors

Table 32: N32 Road Collision Hot Spots/Corridors

Description	Cluster 1
Number of Collisions	5
Collision Type	
Pedestrian	2
Single Vehicle	0
Head-on	1
Angle	1
Rear-end	1
Unknown	0
Light	
Hours of daylight	0
Hours of darkness	5
Unknown	0
Day	
Weekday	5
Weekend	0
Bank holiday weekend	0
Road Surface	
Dry	4
Wet	1
Other/Unknown	0
Junction	
Yes	3
No	2
Speed Limit	
$\leq$ 60 km/h	4
80km/h	0
100km/h	1
120km/h	0
Injuries	
Fatal	1
Serious	2
Minor	3
Not Injured/Unknown	0

.8 Collision Hot Spots/Corridors: National Secondary Roads

The N51 national secondary road which runs from Delvin, Co. Meath to Junction 10 at the M1 (outside Drogheda, Co. Louth). For the purposes of this analysis, the N51 was split into sections. Section 1 runs from Delvin, Co. Meath to M3 junction 9 and section 2 runs from M3 junction 9 to M1 junction 10. Sixty three road traffic collisions were recorded on the N51 road from 2005-2009. The scan statistic was run on 60 road traffic collisions (31 in section 1 and 29 in section 2). Collisions with geographical coordinates located more than 100m from the N51 road were excluded from the analysis. One cluster was identified in section 1 and Table 33 gives detailed description of this cluster. No significant clusters were identified in section 2. A geographical representation of the clusters can be seen in the map: N51 hot spots and corridors.

- **Section 1: Cluster 1**
  - Location:O'Growney St, Athboy, Co. Meath - Main Street, Athboy, Co. Meath
  - Number of collisions: 5
  - Length: 309m

All of the collisions recorded in cluster 1 were multi-vehicle collisions and occurred during the hours of darkness and 20% (1/5) occurred on a weekday. Approximately 60% (3/5) occurred on a dry road surface, 20% (1/5) occurred at a junction and all occurred on sections of road with speed limits 60km/h or less. Five injuries sustained were minor injuries, zero serious injuries and zero fatalities were recorded in this cluster.

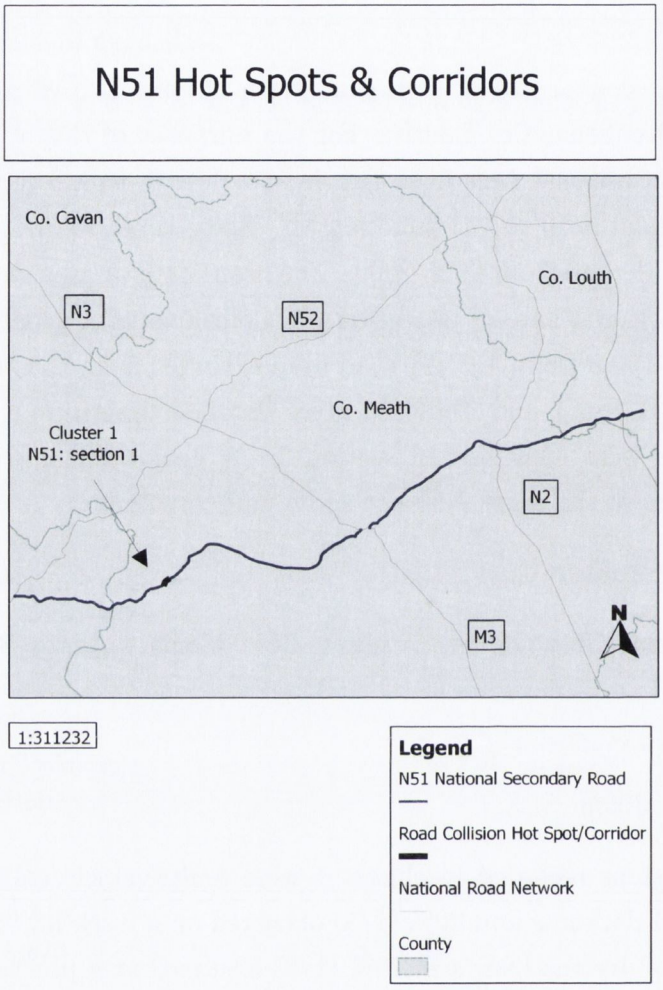


Figure 24: N51 Collision Hot Spots/Corridors

Table 33: N51 Section 1 Road Collision Hot Spots/Corridors

Description	Cluster 1
Number of Collisions	5
Collision Type	
Pedestrian	0
Single Vehicle	0
Head-on	3
Angle	0
Rear-end	2
Unknown	0
Light	
Hours of daylight	0
Hours of darkness	5
Unknown	0
Day	
Weekday	1
Weekend	4
Bank holiday weekend	0
Road Surface	
Dry	3
Wet	2
Other/Unknown	0
Junction	
Yes	1
No	4
Speed Limit	
$\leq$ 60 km/h	5
80km/h	0
100km/h	0
120km/h	0
Injuries	
Fatal	0
Serious	0
Minor	5
Not Injured/Unknown	0

The N54 national secondary road which runs from Monaghan, Co. Monaghan to N54/N3 intersection at Butlersbridge, Co. Cavan. For the purposes of this analysis, the N54 was split into sections. Section 1 runs from Butlersbridge Co. Cavan to the Northern Ireland border and section 2 runs from East of Clonooney, Co. Monaghan to the Northern Ireland border and section 3 runs from Clones, Co. Monaghan to Monaghan, Co. Monaghan. Fifty two road traffic collisions were recorded on the N51 road from 2005-2009. The scan statistic was run on 50 road traffic collisions (11 in section 1 and 39 in section 3). Collisions with geographical coordinates located more than 100m from the N54 road were excluded from the analysis. One cluster was identified in section 1 and Table 34 gives detailed description of this cluster. No significant clusters were identified in sections 2 or 3. A geographical representation of the clusters can be seen in the map: N54 hot spots and corridors.

- **Section 1: Cluster 1**
  - Location: Cavan Road, Co. Cavan south of the Northern Ireland border - Gannons Cross, Co. Cavan
  - Number of collisions: 9
  - Length: 2.4km

Approximately 44.4% (4/9) of the collisions recorded in cluster 1 were multi-vehicle collisions and 66.7% (6/9) occurred during the hours of darkness and 88.9% (8/9) occurred on a weekday. Approximately 66.7% (6/9) occurred on a dry road surface, 33.3% (3/9) occurred at a junction and 77.8% (7/9) occurred on sections of road with speed limits 100km/h. Fourteen injuries sustained were minor injuries, zero serious injuries and zero fatalities were recorded in this cluster.

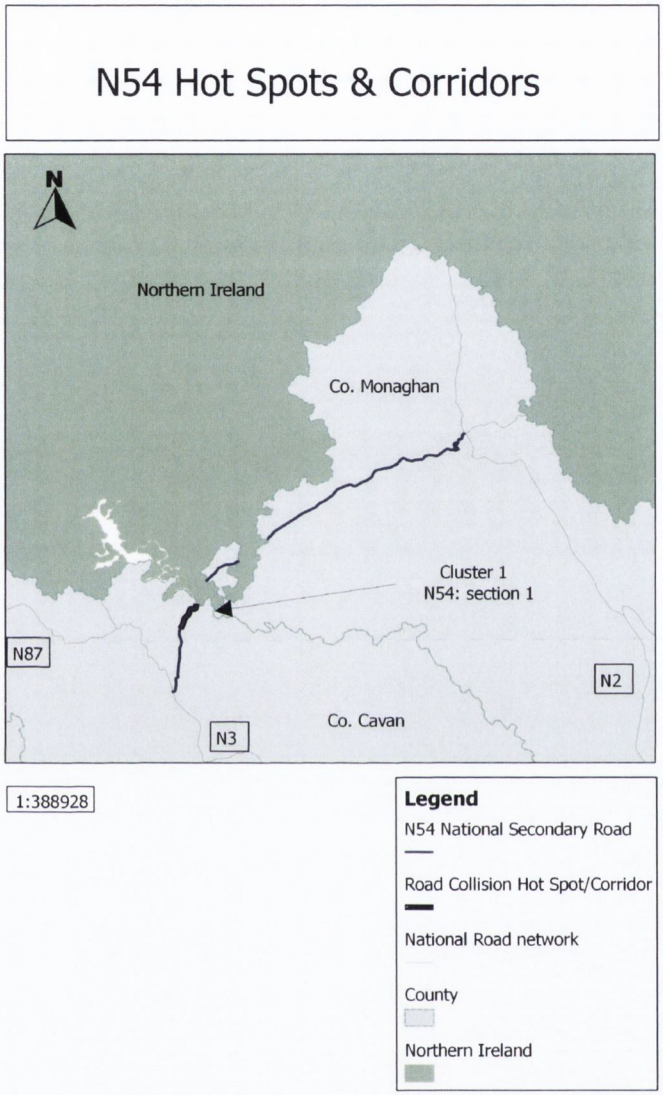


Figure 25: N54 Collision Hot Spots/Corridors

Table 34: N54 Section 1 Road Collision Hot Spots/Corridors

Description	Cluster 1
Number of Collisions	9
Collision Type	
Pedestrian	0
Single Vehicle	2
Head-on	1
Angle	2
Rear-end	1
Unknown	3
Light	
Hours of daylight	2
Hours of darkness	6
Unknown	1
Day	
Weekday	8
Weekend	1
Bank holiday weekend	0
Road Surface	
Dry	6
Wet	2
Other/Unknown	1
Junction	
Yes	3
No	6
Speed Limit	
$\leq$ 60 km/h	0
80km/h	2
100km/h	7
120km/h	0
Injuries	
Fatal	0
Serious	0
Minor	14
Not Injured/Unknown	3

The N55 national secondary road which runs from Athlone, Co. Westmeath to Cavan, Co. Cavan. For the purposes of this analysis, the N55 was split into sections. Section 1 runs from Athlone, Co. Westmeath to N55/N4 intersection near Edgeworthstown, Co. Longford and section 2 runs from Edgeworthstown, Co. Longford to Cavan, Co. Cavan. Ninety seven road traffic collisions were recorded on the N55 road from 2005-2009. The scan statistic was run on 91 road traffic collisions (39 in section 1 and 52 in section 2). Collisions with geographical coordinates located more than 100m from the N55 road were excluded from the analysis. One cluster was identified in section 2 and Table 35 gives detailed description of this cluster. No significant clusters were identified in section 1. A geographical representation of the clusters can be seen in the map: N55 hot spots and corridors.

- **Section 2: Cluster 1**
  - Location: North East of Cranalagh More, Co. Longford - North East of Cranalagh More, Co. Longford
  - Number of collisions: 6
  - Length: 179m

Approximately 66.7% (4/6) of the collisions recorded in cluster 1 were multi-vehicle collisions and 33.3% (2/6) occurred during the hours of darkness and all occurred on a weekday. Approximately 66.7% (4/6) occurred on a dry road surface, 33.3% (2/6) occurred at a junction and all occurred on sections of road with speed limits 100km/h. Eleven injuries sustained were minor injuries, zero serious injuries and zero fatalities were recorded in this cluster.

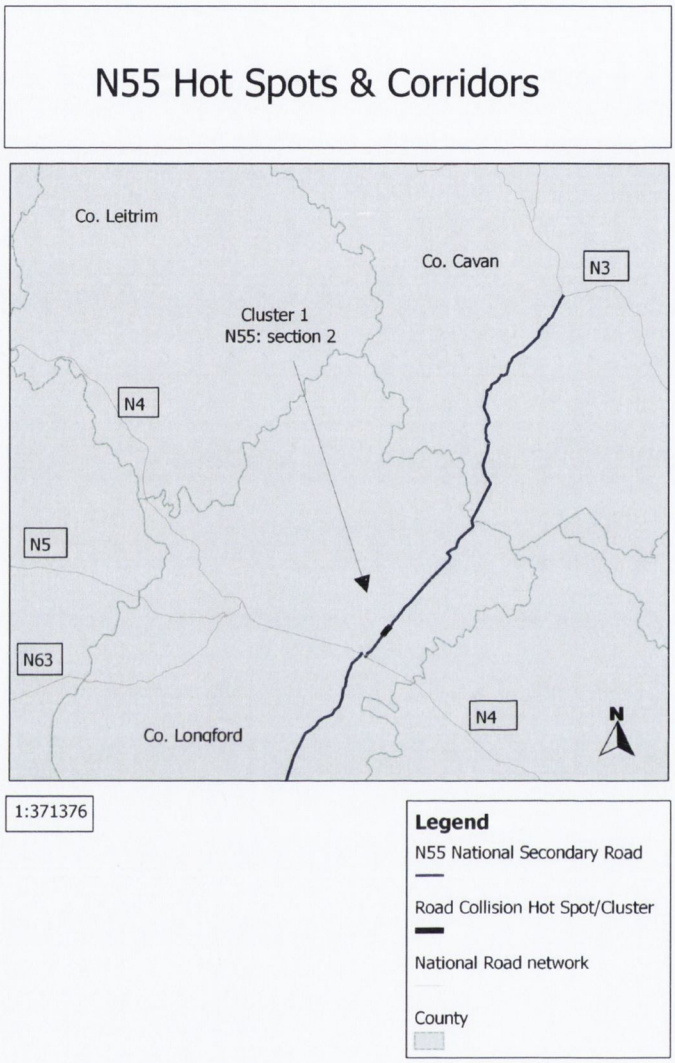


Figure 26: N55 Collision Hot Spots/Corridors

Table 35: N55 Section 2 Road Collision Hot Spots/Corridors

Description	Cluster 1
Number of Collisions	6
Collision Type	
Pedestrian	1
Single Vehicle	0
Head-on	1
Angle	2
Rear-end	1
Unknown	1
Light	
Hours of daylight	4
Hours of darkness	2
Unknown	0
Day	
Weekday	6
Weekend	0
Bank holiday weekend	0
Road Surface	
Dry	4
Wet	0
Other/Unknown	2
Junction	
Yes	2
No	4
Speed Limit	
$\leq$ 60 km/h	0
80km/h	0
100km/h	6
120km/h	0
Injuries	
Fatal	0
Serious	0
Minor	11
Not Injured/Unknown	1

The N56 national secondary road which runs from Donegal, Co. Donegal to Letterkenny, Co. Donegal. One hundred and ninety two road traffic collisions were recorded on the N56 road from 2005-2009. The scan statistic was run on 178 road traffic collisions as collisions with geographical coordinates located more than 100m from the N56 road were excluded from the analysis. Two clusters were identified and Table 36 gives detailed description of each cluster. A geographical representation of the clusters can be seen in the map: N56 hot spots and corridors.

- **Cluster 1**
  - Location: North West of Knocknabollan, Co. Donegal - Letterkenny, Co. Donegal
  - Number of collisions: 36
  - Length: 11km

Approximately 44.4% (16/36) of the collisions recorded in cluster 1 were multi-vehicle collisions, 19.4% (7/36) were single vehicle collisions, 80.5% (29/36) occurred during the hours of darkness and 69.4% (25/36) occurred on a weekday. Approximately 44.4% (16/36) occurred on a dry road surface, 22.2% (8/36) occurred at a junction and 75% (27/36) occurred on sections of road with speed limits 100km/h. Forty seven injuries sustained were minor injuries, five serious injuries and zero fatalities were recorded in this cluster.

- **Cluster 2**
  - Location: West of Mountcharles, Co. Donegal - North West of Turrishill, Co. Donegal
  - Number of collisions: 8
  - Length: 752m

Approximately 37.5% (3/8) of the collisions recorded in cluster 2 were multi-vehicle collisions, 37.5% (3/8) were single vehicle collisions, 87.5% (7/8) occurred during the hours of darkness and 62.5% (5/8) occurred on a weekday. Approximately 62.5% (5/8) occurred on a dry road surface, 12.5% (1/8) occurred at a junction and 87.5% (7/8) occurred on sections of road with speed limits 100km/h. Thirteen injuries sustained were minor injuries, two serious injuries and zero fatalities were recorded in this cluster.

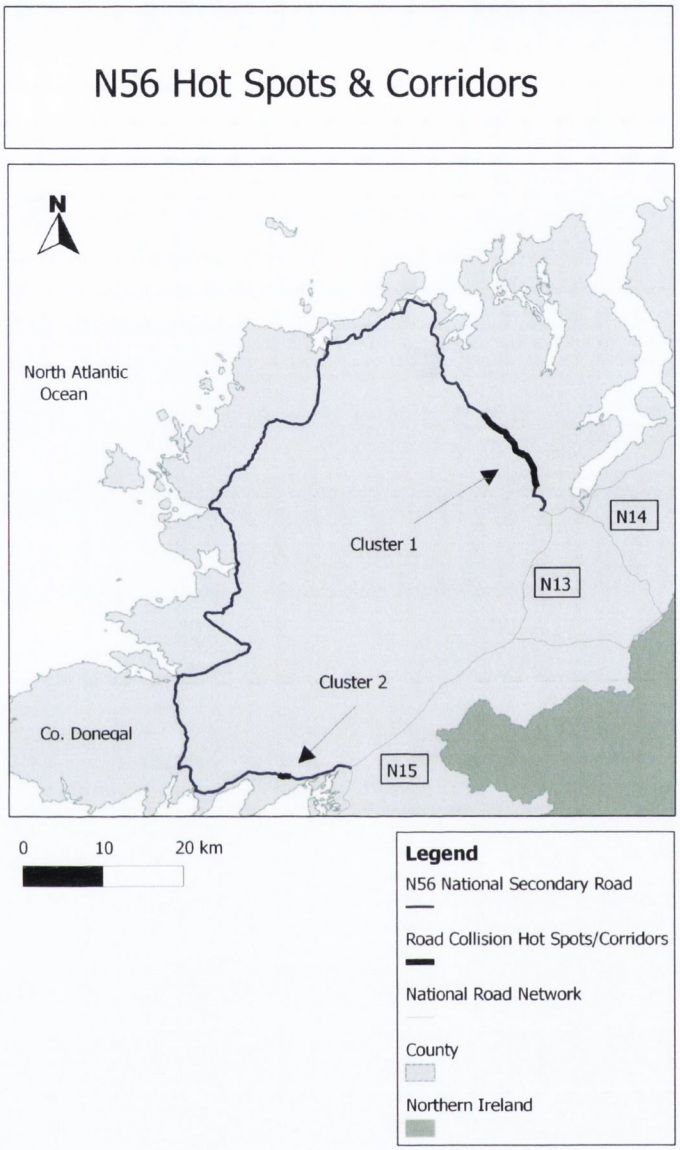


Figure 27: N56 Collision Hot Spots/Corridors

Table 36: N56 Road Collision Hot Spots/Corridors

Description	Cluster 1	Cluster 2
Number of Collisions	36	8
Collision Type		
Pedestrian	2	0
Single Vehicle	7	3
Head-on	6	2
Angle	4	1
Rear-end	6	0
Unknown	11	2
Light		
Hours of daylight	7	1
Hours of darkness	29	7
Unknown	0	0
Day		
Weekday	25	5
Weekend	9	3
Bank holiday weekend	2	0
Road Surface		
Dry	16	5
Wet	18	3
Other/Unknown	2	0
Junction		
Yes	8	1
No	28	7
Speed Limit		
$\leq$ 60 km/h	7	1
80km/h	2	0
100km/h	27	7
120km/h	0	0
Injuries		
Fatal	0	0
Serious	5	2
Minor	47	13
Not Injured/Unknown	3	8

The N59 national secondary road which runs from N59/N6 intersection near Galway City, Co. Galway to N59/N4 intersection south of Sligo, Co. Sligo. For the purposes of this analysis, the N59 was split into sections. Section 1 runs from N59/N6 intersection near Galway City, Co. Galway to N59/N5 intersection Westport, Co. Mayo and section 2 runs from Westport, Co. Mayo to N59/N4 intersection south of Sligo, Co. Sligo. One hundred and eight nine road traffic collisions were recorded on the N59 road from 2005-2009. The scan statistic was run on 186 road traffic collisions (80 in section 1 and 106 in section 2). Collisions with geographical coordinates located more than 100m from the N59 road were excluded from the analysis. One cluster was identified in section 1 and two clusters were identified in section 2. Tables 37 - 38 gives detailed description of each cluster. No significant clusters were identified in section 1. A geographical representation of the clusters can be seen in the map: N59 hot spots and corridors.

- **Section 1: Cluster 1**
  - Location: Quay Street, Westport, Co. Mayo - Newport St, Westport, Co. Mayo
  - Number of collisions: 6
  - Length: 810m

Approximately 50% (3/6) of the collisions recorded in cluster 1 were pedestrian involved collisions and 33.3% (2/6) were multi-vehicle collisions. All recorded collisions occurred during the hours of darkness and 66.7% (4/6) occurred on a weekday. Approximately 50% (3/6) occurred on a dry road surface, 50% (3/6) occurred at a junction and all occurred on sections of road with speed limits 60km/h or less. Five injuries sustained were minor injuries, three serious injuries and zero fatalities were recorded in this cluster.

- **Section 2: Cluster 1**
  - Location: Sligo Road, Ballina, Co. Mayo - Dillon Terrace, Ballina, Co. Mayo
  - Number of collisions: 17
  - Length: 1.5km

Approximately 35.3% (7/17) were multi-vehicle collisions and 29.4% (5/17) of the collisions recorded in cluster 1 were single vehicle collisions. Eighty eight percent (15/17) of recorded collisions occurred during the hours of darkness and 70.6% (12/17) occurred on a weekday. Approximately 35.3% (7/17) occurred on a dry road surface, 23.5% (4/17) occurred at a junction and 88.2% (15/17) occurred on sections of road with speed limits 60km/h or less. Eighteen injuries sustained were minor injuries, three serious injuries and two fatalities were recorded in this cluster.

- **Section 2: Cluster 2**
  - Location: Newport Road Intersection with the Paddock, Westport, Co. Mayo - North Mall/Newport Street Intersection, Westport, Co. Mayo
  - Number of collisions: 5
  - Length: 241m

Approximately 40% (2/5) were single vehicle collisions and 40% (2/5) of the collisions recorded in cluster 1 were pedestrian involved collisions. All collisions recorded occurred during the hours of darkness and 60% (3/5) occurred on a weekday. Approximately 60% (3/5) occurred on a dry road surface, 40% (2/5) occurred at a junction and all occurred on sections of road with speed limits 60km/h or less. Five injuries sustained were minor injuries, zero serious injuries and zero fatalities were recorded in this cluster.

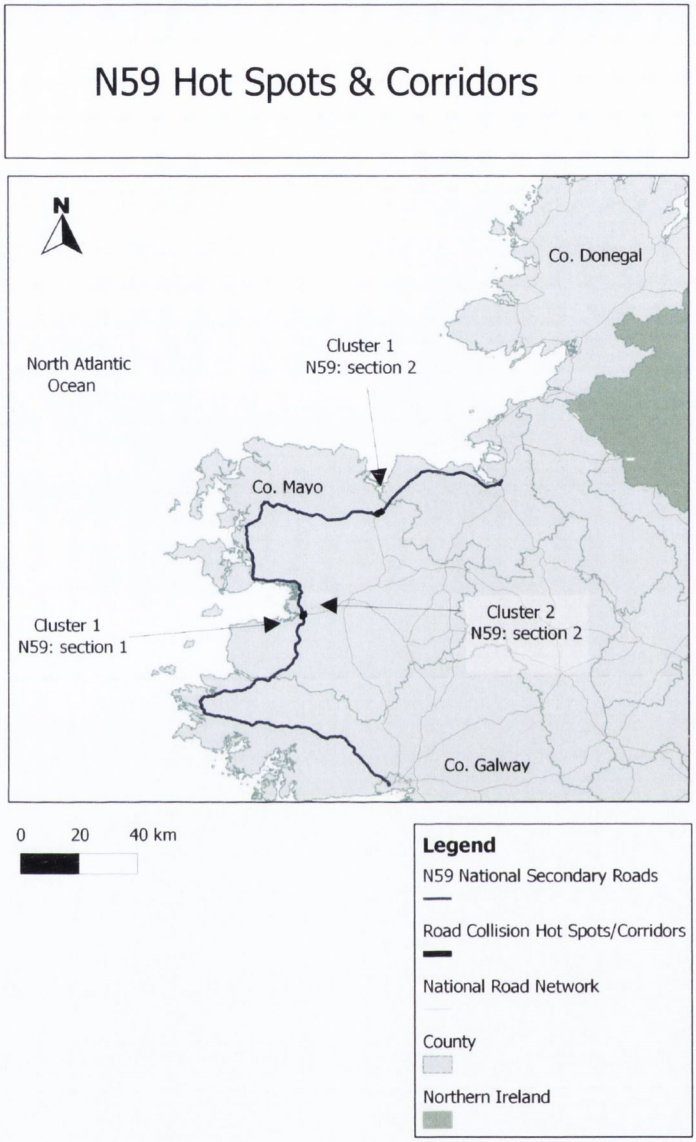


Figure 28: N59 Collision Hot Spots/Corridors

Table 37: N59 Section 1 Road Collision Hot Spots/Corridors

Description	Cluster 1
Number of Collisions	6
Collision Type	
Pedestrian	3
Single Vehicle	1
Head-on	0
Angle	2
Rear-end	0
Unknown	0
Light	
Hours of daylight	0
Hours of darkness	6
Unknown	0
Day	
Weekday	4
Weekend	2
Bank holiday weekend	0
Road Surface	
Dry	3
Wet	3
Other/Unknown	0
Junction	
Yes	3
No	3
Speed Limit	
$\leq$ 60 km/h	6
80km/h	0
100km/h	0
120km/h	0
Injuries	
Fatal	0
Serious	3
Minor	5
Not Injured/Unknown	0

Table 38: N59 Section 2 Road Collision Hot Spots/Corridors

Description	Cluster 1	Cluster 2
Number of Collisions	17	5
Collision Type		
Pedestrian	3	2
Single Vehicle	5	2
Head-on	1	0
Angle	2	1
Rear-end	4	0
Unknown	2	0
Light		
Hours of daylight	1	0
Hours of darkness	15	5
Unknown	1	0
Day		
Weekday	12	3
Weekend	5	2
Bank holiday weekend	0	0
Road Surface		
Dry	7	3
Wet	8	2
Other/Unknown	2	0
Junction		
Yes	4	2
No	13	3
Speed Limit		
$\leq$ 60 km/h	15	5
80km/h	1	0
100km/h	1	0
120km/h	0	0
Injuries		
Fatal	2	0
Serious	3	0
Minor	18	5
Not Injured/Unknown	0	0

The N61 national secondary road which runs from N61/N4 intersection, Boyle, Co. Roscommon to Athlone, Co. Westmeath. Seventy three road traffic collisions were recorded on the N61 road from 2005-2009. The scan statistic was run on 72 road traffic collisions as collisions with geographical coordinates located more than 100m from the N61 road were excluded from the analysis. One clusters was identified and Table 39 gives detailed description of each cluster. A geographical representation of the clusters can be seen in the map: N61 hot spots and corridors.

- **Cluster 1**
  - Location: Near Casheltauna, Co. Roscommon - Athlone Road, Roscommon, Co. Roscommon
  - Number of collisions: 27
  - Length: 11.6km

Approximately 51.9% (14/27) of the collisions recorded in cluster 1 were multi-vehicle collisions, 37% (10/27) were single vehicle collisions, 70.4% (19/27) occurred during the hours of darkness and 74.1% (20/27) occurred on a weekday. Approximately 51.9% (14/27) occurred on a dry road surface, 22.2% (6/27) occurred at a junction and 70.4% (19/27) occurred on sections of road with speed limits 100km/h. Thirty four injuries sustained were minor injuries, eleven serious injuries and two fatalities were recorded in this cluster.

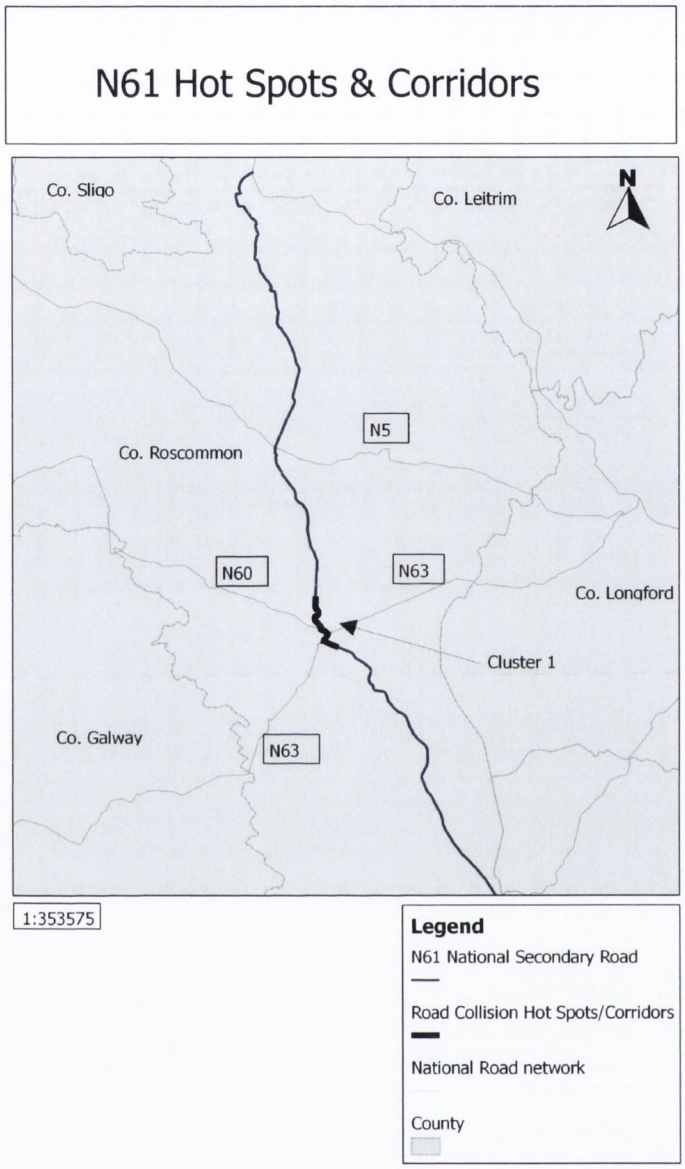


Figure 29: N61 Collision Hot Spots/Corridors

Table 39: N61 Road Collision Hot Spots/Corridors

Description	Cluster 1
Number of Collisions	27
Collision Type	
Pedestrian	1
Single Vehicle	10
Head-on	4
Angle	2
Rear-end	8
Unknown	2
Light	
Hours of daylight	8
Hours of darkness	19
Unknown	0
Day	
Weekday	20
Weekend	7
Bank holiday weekend	0
Road Surface	
Dry	14
Wet	10
Other/Unknown	3
Junction	
Yes	6
No	21
Speed Limit	
$\leq$ 60 km/h	4
80km/h	4
100km/h	19
120km/h	0
Injuries	
Fatal	2
Serious	11
Minor	34
Not Injured/Unknown	3

The N67 national secondary road which runs from N67/N18 intersection near Galway City, Co. Galway to Tarbert, Co. Kerry (via ferry). For the purposes of this analysis, the N67 was split into sections. Section 1 runs from Tarbert, Co. Kerry to the Ferry terminal at Arbert island and section 2 runs from Killimer, Co. Clare to N67/N18 intersection near Galway City, Co. Galway. Eighty four road traffic collisions were recorded on the N67 road from 2005-2009. The scan statistic was run on 83 road traffic collisions (all in section 2). Collisions with geographical coordinates located more than 100m from the N67 road were excluded from the analysis. One cluster was identified in section 1 and Table 40 gives detailed description of this cluster. A geographical representation of the cluster can be seen in the map: N67 hot spots and corridors.

- **Section 1: Cluster 1**
  - Location: N67/Glenveil Road intersection, Co. Clare - Ballycarraeile, Co. Clare
  - Number of collisions: 23
  - Length: 12.3km

Approximately 39.1% (9/23) of the collisions recorded in cluster 1 were multi-vehicle involved collisions and 21.7% (5/23) were pedestrian involved collisions. Seventy four percent (17/23) of collisions occurred during the hours of darkness and 60.9% (14/23) occurred on a weekday. Approximately 65.2% (15/23) occurred on a dry road surface, 30.4% (7/23) occurred at a junction and 60.9% (14/23) occurred on sections of road with speed limits 100km/h. Twenty injuries sustained were minor injuries, one serious injury and three fatalities were recorded in this cluster.

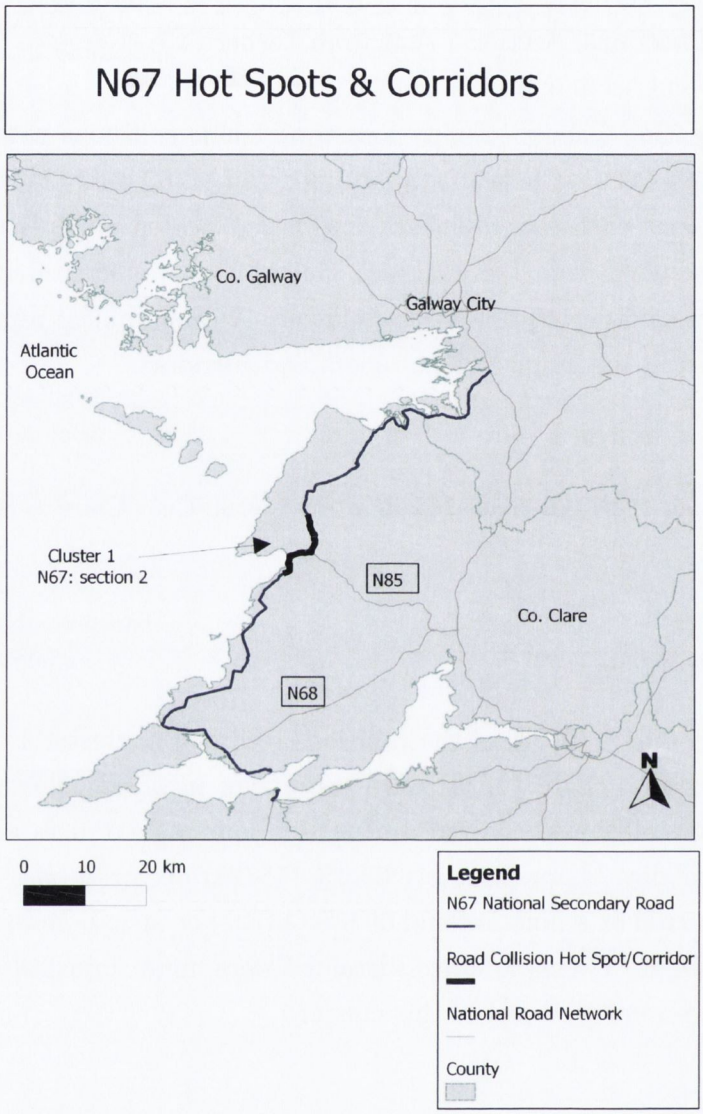


Figure 30: N67 Collision Hot Spots/Corridors

Table 40: N67 Section 2 Road Collision Hot Spots/Corridors

Description	Cluster 1
Number of Collisions	23
Collision Type	
Pedestrian	5
Single Vehicle	4
Head-on	6
Angle	2
Rear-end	1
Unknown	5
Light	
Hours of daylight	5
Hours of darkness	17
Unknown	1
Day	
Weekday	14
Weekend	9
Bank holiday weekend	0
Road Surface	
Dry	15
Wet	7
Other/Unknown	1
Junction	
Yes	7
No	16
Speed Limit	
$\leq$ 60 km/h	9
80km/h	0
100km/h	14
120km/h	0
Injuries	
Fatal	3
Serious	1
Minor	20
Not Injured/Unknown	1

The N69 national secondary road runs from Limerick City, Co. Limerick to Tralee, Co. Kerry. One hundred and forty seven road traffic collisions were recorded on the N69 road from 2005-2009. The scan statistic was run on 144 road traffic collisions. Collisions with geographical coordinates located more than 100m from the N69 road were excluded from the analysis. Three clusters were identified and Table 41 gives detailed description of each cluster. A geographical representation of the clusters can be seen in the map: N69 hot spots and corridors.

- **Cluster 1**
  - Location: R521 (Askeaton Rd) / N69 Intersection, Co. Limerick
  - Number of collisions: 5
  - Length: 39m

Approximately 80% (4/5) of the collisions recorded in cluster 1 were multi-vehicle involved collisions, all occurred during the hours of darkness and 80% (4/5) occurred on a weekday. Approximately 60% (3/5) occurred on a dry road surface, all occurred at a junction and all occurred on sections of road with speed limits 100km/h. Eight injuries sustained were minor injuries, zero serious injuries and zero fatalities were recorded in this cluster.

- **Cluster 2**
  - Location: Glenameade Road, Co. Limerick - West of Coolbeg, Co. Limerick
  - Number of collisions: 13
  - Length: 1.8km

Approximately 46.2% (6/13) of the collisions recorded in cluster 2 were multi-vehicle involved collisions and 46.2% (6/13) were single vehicle collisions. Seventy seven percent (10/13) occurred during the hours of darkness and 69.2% (9/13) occurred on a weekday. Approximately 69.2% (9/13) occurred on a dry road surface, 7.6% (1/13) occurred at a junction and 76.9% (10/13) occurred on sections of road with speed limits 100km/h. Eighteen injuries sustained were minor injuries, two serious injuries and three fatalities were recorded in this cluster.

- **Cluster 3**
  - Location: Clarina, Co. Limerick - N69/Ballybrown (Ed Clarina) intersection, Co. Limerick

- Number of collisions: 6
- Length: 290m

Approximately 50% (3/6) of the collisions recorded in cluster 3 were multi-vehicle involved collisions and 33.3% (2/6) were single vehicle collisions. Eighty three percent (5/6) occurred during the hours of darkness and 50% (3/6) occurred on a weekday. Approximately 16.7% (1/6) occurred on a dry road surface, 50% (3/6) occurred at a junction and 66.7% (4/6) occurred on sections of road with speed limits 60km/h or less. Seven injuries sustained were minor injuries, two serious injuries and zero fatalities were recorded in this cluster.

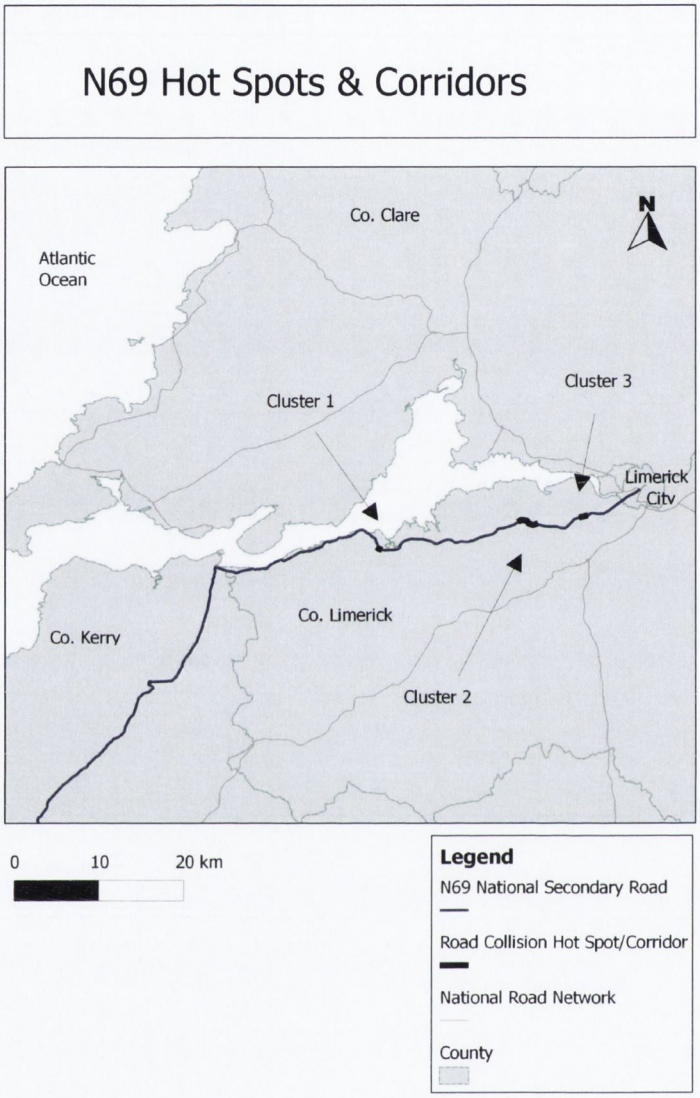


Figure 31: N69 Collision Hot Spots/Corridors

Table 41: N69 Road Collision Hot Spots/Corridors

Description	Cluster 1	Cluster 2	Cluster 3
Number of Collisions	5	13	6
Collision Type			
Pedestrian	0	0	1
Single Vehicle	0	6	2
Head-on	1	2	1
Angle	2	2	2
Rear-end	1	2	0
Unknown	1	1	0
Light			
Hours of daylight	0	3	1
Hours of darkness	5	10	5
Unknown	0	0	0
Day			
Weekday	4	9	3
Weekend	1	3	3
Bank holiday weekend	0	1	0
Road Surface			
Dry	3	9	1
Wet	2	3	4
Other/Unknown	0	1	1
Junction			
Yes	5	1	3
No	0	12	3
Speed Limit			
$\leq$ 60 km/h	0	1	4
80km/h	0	2	0
100km/h	5	10	2
120km/h	0	0	0
Injuries			
Fatal	0	3	0
Serious	0	2	2
Minor	8	18	7
Not Injured/Unknown	0	0	0

The N70 national secondary road runs from Kenmare, Co. Kerry to Tralee, Co. Kerry. Eight nine road traffic collisions were recorded on the N70 road from 2005-2009. The scan statistic was run on 87 road traffic collisions. Collisions with geographical coordinates located more than 100m from the N70 road were excluded from the analysis. One cluster was identified and Table 42 gives detailed description of this cluster. A geographical representation of the cluster can be seen in the map: N70 hot spots and corridors.

- **Cluster 1**
  - Location: Tralee, Co. Kerry - Tinnahally, Co. Kerry
  - Number of collisions: 36
  - Length: 22.3km

Approximately 52.8% (19/36) of the collisions recorded in cluster 1 were multi-vehicle involved collisions, 80.6% (29/36) occurred during the hours of darkness and 61.1% (22/36) occurred on a weekday. Approximately 58.3% (21/36) occurred on a dry road surface, 22.2% (8/36) occurred at a junction and 61.1% (22/36) occurred on sections of road with speed limits 100km/h. Forty nine injuries sustained were minor injuries, two serious injuries and one fatality were recorded in this cluster.

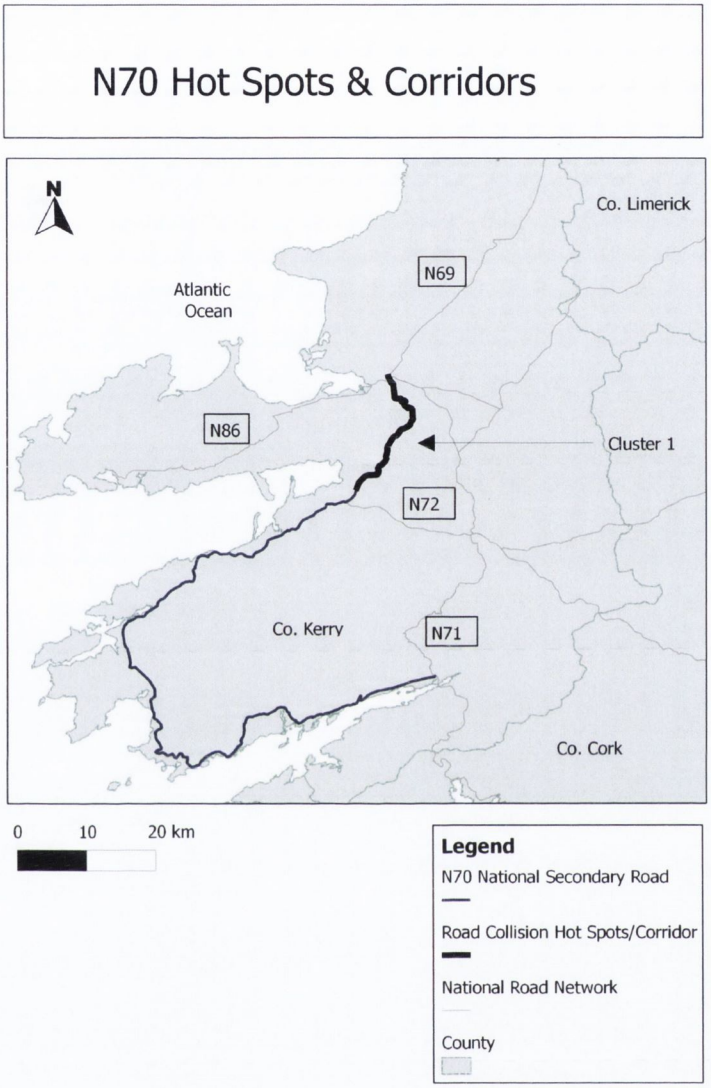


Figure 32: N70 Collision Hot Spots/Corridors

Table 42: N70 Road Collision Hot Spots/Corridors

Description	Cluster 1
Number of Collisions	36
Collision Type	
Pedestrian	4
Single Vehicle	6
Head-on	11
Angle	3
Rear-end	5
Unknown	7
Light	
Hours of daylight	6
Hours of darkness	29
Unknown	1
Day	
Weekday	22
Weekend	13
Bank holiday weekend	1
Road Surface	
Dry	21
Wet	14
Other/Unknown	1
Junction	
Yes	8
No	28
Speed Limit	
$\leq$ 60 km/h	9
80km/h	5
100km/h	22
120km/h	0
Injuries	
Fatal	1
Serious	2
Minor	49
Not Injured/Unknown	3

The N71 national secondary road runs from Cork City, Co. Cork to Killarney, Co. Kerry. For the purposes of this analysis, the N71 was split into sections. Section 1 runs from Killarney, Co. Kerry to N71/N28 intersection. Section 2 runs from N28 (South Ring Road)/N22 intersection, Cork city, Co. Cork. One hundred and ninety eight road traffic collisions were recorded on the N71 road from 2005-2009. The scan statistic was run on 187 road traffic collisions (173 in section 1 and 14 in section 2). Collisions with geographical coordinates located more than 100m from the N71 road were excluded from the analysis. One cluster was identified in section 1 and Table 43 gives detailed description of this cluster. A geographical representation of the cluster can be seen in the map: N71 hot spots and corridors.

- **Section 1: Cluster 1**
  - Location: Churraigh, Co. Cork - Hawkes Road, Cork, Co. Cork
  - Number of collisions: 90
  - Length: 51km

Approximately 60% (54/90) of the collisions recorded in cluster 1 were multi-vehicle involved collisions and 20% (18/90) were single vehicle collisions. Eighty four percent (76/90) of collisions occurred during the hours of darkness and 70% (63/90) occurred on a weekday. Approximately 65.6% (59/90) occurred on a dry road surface, 31.1% (28/90) occurred at a junction and 71.1% (64/90) occurred on sections of road with speed limits 100km/h. One hundred and fifteen injuries sustained were minor injuries, fourteen serious injuries and eight fatalities were recorded in this cluster.

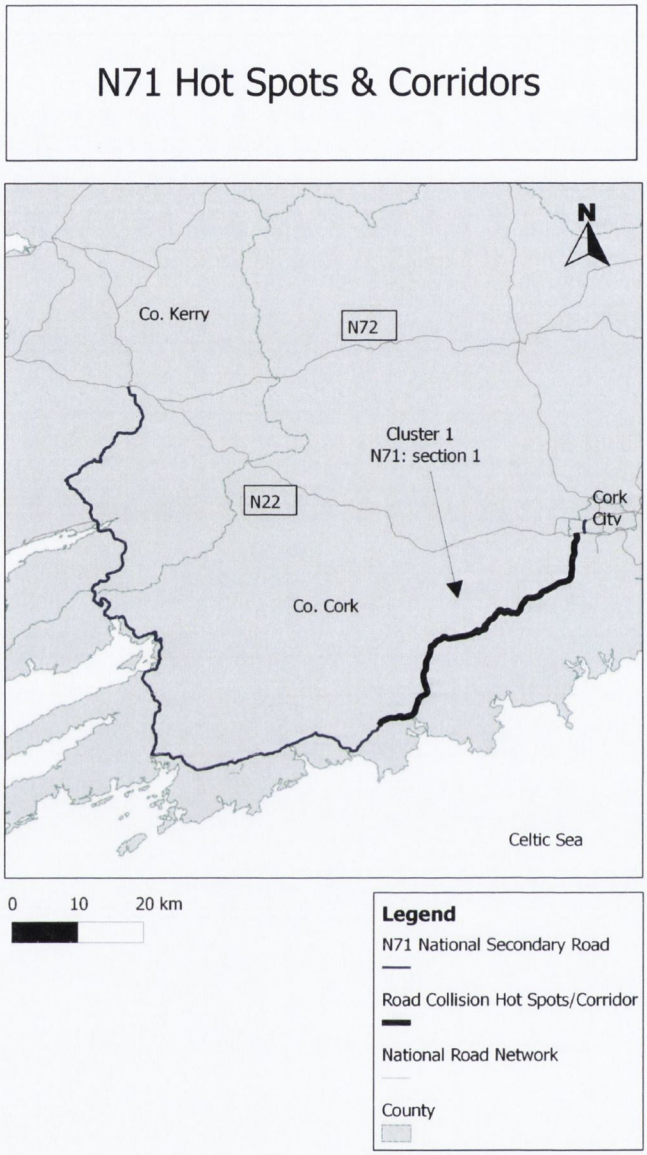


Figure 33: N71 Collision Hot Spots/Corridors

Table 43: N71 Section 1 Road Collision Hot Spots/Corridors

Description	Cluster 1
Number of Collisions	90
Collision Type	
Pedestrian	8
Single Vehicle	18
Head-on	17
Angle	11
Rear-end	26
Unknown	10
Light	
Hours of daylight	12
Hours of darkness	76
Unknown	2
Day	
Weekday	63
Weekend	23
Bank holiday weekend	4
Road Surface	
Dry	59
Wet	29
Other/Unknown	2
Junction	
Yes	28
No	62
Speed Limit	
$\leq$ 60 km/h	24
80km/h	2
100km/h	64
120km/h	0
Injuries	
Fatal	8
Serious	14
Minor	115
Not Injured/Unknown	3

The N72 national secondary road runs from N70/N72 intersection, Killorglin, Co. Kerry - N70/N25 intersection, Dungarvan, Co. Waterford. For the purposes of this analysis, the N72 was split into sections. Section 1 runs from N70/N72 intersection, Killorglin, Co. Kerry to Killarney, Co. Kerry. Section 2 runs from N72/N22 intersection, south east of Killarney, Co. Kerry - N70/N25 intersection, Dungarvan, Co. Waterford. One hundred and eighty three road traffic collisions were recorded on the N72 road from 2005-2009. The scan statistic was run on 174 road traffic collisions (19 in section 1 and 155 in section 2). Collisions with geographical coordinates located more than 100m from the N72 road were excluded from the analysis. Two clusters were identified in section 2 and Table 44 gives detailed description of this cluster. No significant clusters were identified in section 1. A geographical representation of the cluster can be seen in the map: N72 hot spots and corridors.

- **Section 2: Cluster 1**
  - Location: R579/N72 Intersection, Ballyquirk, Co. Cork
  - Number of collisions: 5
  - Length: 17m

All of the collisions recorded in cluster 1 were multi-vehicle involved collisions, all occurred during the hours of darkness and occurred on a weekday. Approximately 20% (1/5) occurred on a dry road surface, all occurred at a junction and all occurred on sections of road with speed limits 100km/h. Seven injuries sustained were minor injuries, one serious injury and zero fatalities were recorded in this cluster.

- **Section 2: Cluster 2**
  - Location: West of The Fair Field, Dromagh, Co. Cork - The Fair Field, Co. Cork
  - Number of collisions: 5
  - Length: 221m

Approximately 60% (3/5) of the collisions recorded in cluster 1 were multi-vehicle involved collisions, all occurred during the hours of darkness and 80% (4/5) occurred on a weekday. Approximately 40% (2/5) occurred on a dry road surface, zero occurred at a junction and all occurred on sections of road with speed limits 100km/h. Five injuries sustained were minor injuries, two serious injuries and zero fatalities were recorded in this cluster.

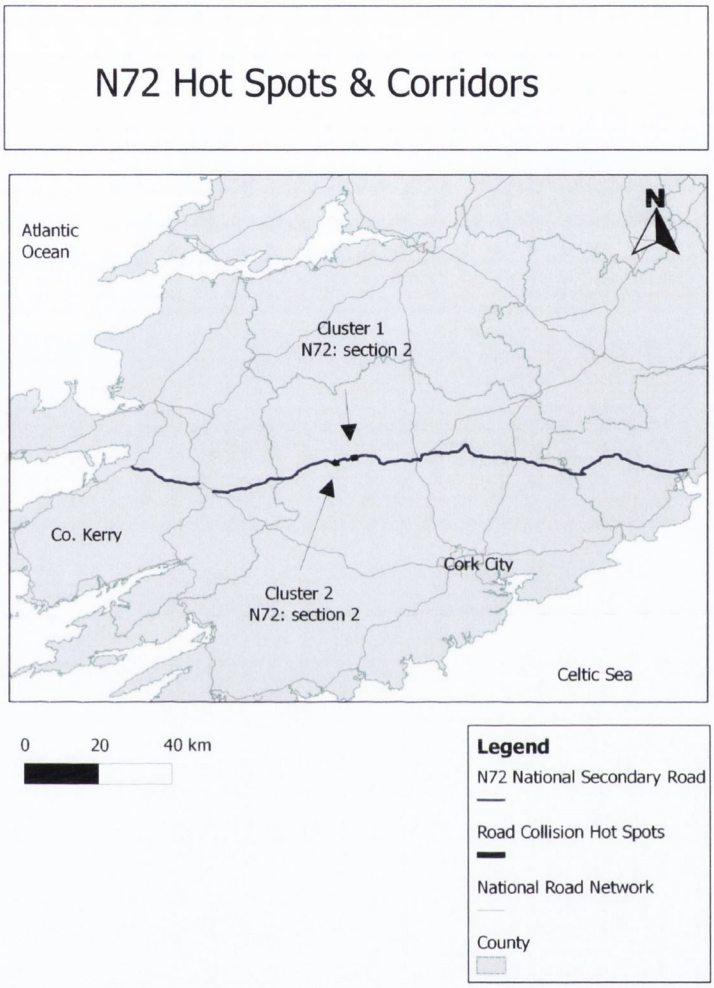


Figure 34: N72 Collision Hot Spots/Corridors

Table 44: N72 Section 2 Road Collision Hot Spots/Corridors

Description	Cluster 1	Cluster 2
Number of Collisions	5	5
Collision Type		
Pedestrian	0	0
Single Vehicle	0	1
Head-on	1	3
Angle	1	0
Rear-end	3	0
Unknown	0	1
Light		
Hours of daylight	0	0
Hours of darkness	5	5
Unknown	0	0
Day		
Weekday	5	4
Weekend	0	1
Bank holiday weekend	0	0
Road Surface		
Dry	1	2
Wet	4	3
Other/Unknown	0	0
Junction		
Yes	5	0
No	0	5
Speed Limit		
$\leq$ 60 km/h	0	0
80km/h	0	0
100km/h	5	5
120km/h	0	0
Injuries		
Fatal	0	0
Serious	1	2
Minor	7	5
Not Injured/Unknown	0	0

The N76 national secondary road runs from Kilkenny, Co. Kilkenny to N76/N24 intersection east of Clonmel, Co. Tipperary. Fifty road traffic collisions were recorded on the N76 road from 2005-2009. The scan statistic was run on 48 road traffic collisions. Collisions with geographical coordinates located more than 100m from the N76 road were excluded from the analysis. One cluster was identified and Table 45 gives detailed description of this cluster. A geographical representation of the cluster can be seen in the map: N76 hot spots and corridors.

- **Cluster 1**
  - Location: Rathaleek, Co. Kilkenny - Callan Road, Co. Kilkenny
  - Number of collisions: 12
  - Length: 1.2km

Approximately 50% (6/12) of the collisions recorded in cluster 1 were multi-vehicle involved collisions, 33.3% (4/12) were single vehicle collisions, 75% (9/12) occurred during the hours of darkness and 50% (6/12) occurred on a weekday. Approximately 66.7% (8/12) occurred on a dry road surface, 16.7% (2/12) occurred at a junction and 75% (9/12) occurred on sections of road with speed limits 100km/h. Seventeen injuries sustained were minor injuries, four serious injuries and zero fatalities were recorded in this cluster.

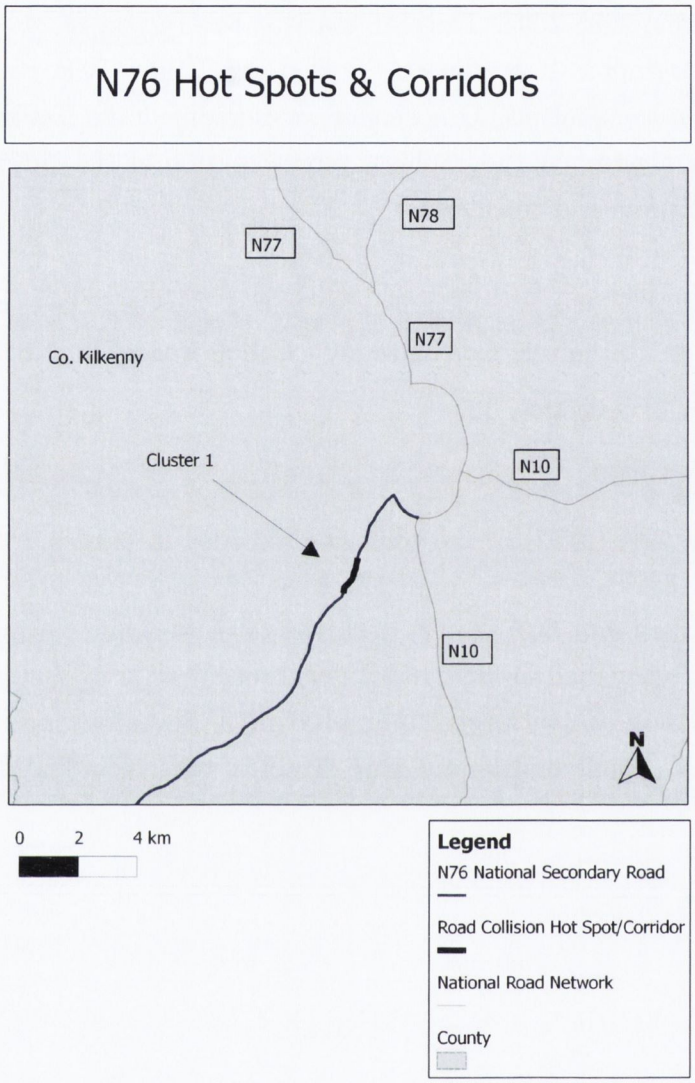


Figure 35: N76 Collision Hot Spots/Corridors

Table 45: N76 Road Collision Hot Spots/Corridors

Description	Cluster 1
Number of Collisions	12
Collision Type	
Pedestrian	1
Single Vehicle	4
Head-on	3
Angle	2
Rear-end	1
Unknown	1
Light	
Hours of daylight	3
Hours of darkness	9
Unknown	0
Day	
Weekday	6
Weekend	6
Bank holiday weekend	0
Road Surface	
Dry	8
Wet	3
Other/Unknown	1
Junction	
Yes	2
No	10
Speed Limit	
$\leq$ 60 km/h	2
80km/h	1
100km/h	9
120km/h	0
Injuries	
Fatal	0
Serious	4
Minor	17
Not Injured/Unknown	0

The N77 national secondary road runs from M7 junction 17 - N77/N10 intersection, Kilkenny, Co. Kilkenny. Originally (before the opening of the M8 motorway in 2010) the N77 ran from Durrow, Co. Laois to N77/N10 intersection, thus the section of road from M7 junction 17 to Durrow, Co. Laois was previously part of the N8 national primary route. Twenty seven road traffic collisions were recorded on the N77 road from 2005-2009. The scan statistic was run on 22 road traffic collisions. Collisions with geographical coordinates located more than 100m from the N77 road were excluded from the analysis. One cluster was identified and Table 46 gives detailed description of this cluster. A geographical representation of the cluster can be seen in the map: N77 hot spots and corridors.

- **Cluster 1**
  - Location: Suttonsrath, Co. Kilkenny - Castlecomer Road Co. Kilkenny
  - Number of collisions: 11
  - Length: 4.2km

Approximately 45.5% (5/11) of the collisions recorded in cluster 1 were multi-vehicle involved collisions, 36.4% (4/11) were single vehicle collisions, 81.8% (9/11) occurred during the hours of darkness and 63.6% (7/11) occurred on a weekday. Approximately 27.3% (3/11) occurred on a dry road surface, 9% (1/11) occurred at a junction and 72.7% (8/11) occurred on sections of road with speed limits 100km/h. Twelve injuries sustained were minor injuries, two serious injuries and one fatality were recorded in this cluster.

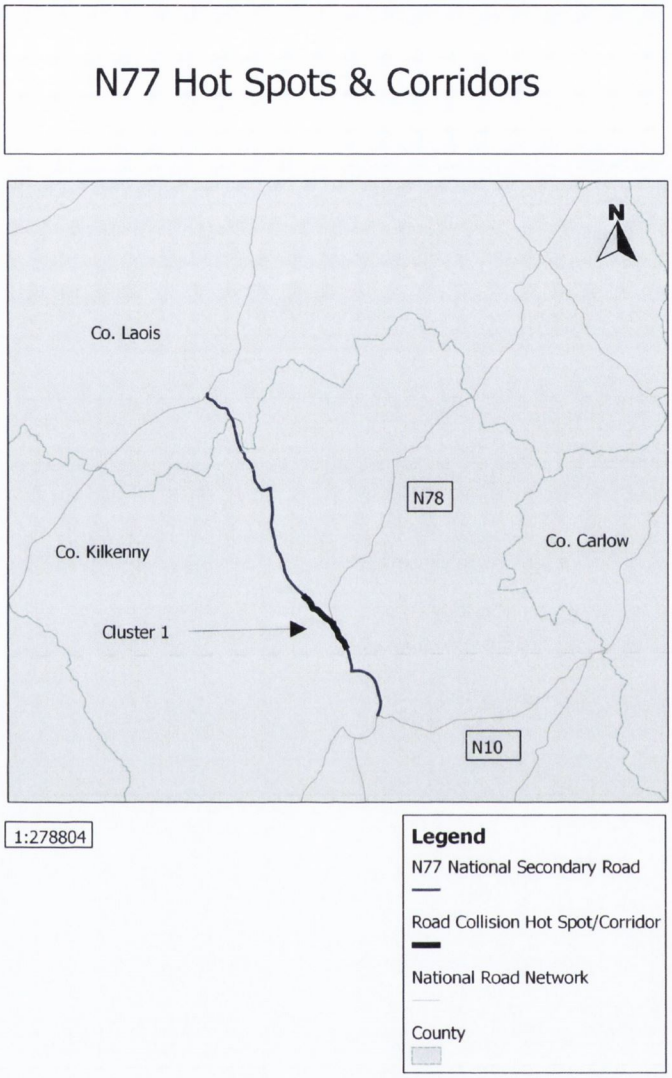


Figure 36: N77 Collision Hot Spots/Corridors

Table 46: N77 Road Collision Hot Spots/Corridors

Description	Cluster 1
Number of Collisions	11
Collision Type	
Pedestrian	0
Single Vehicle	4
Head-on	4
Angle	0
Rear-end	1
Unknown	2
Light	
Hours of daylight	2
Hours of darkness	9
Unknown	0
Day	
Weekday	7
Weekend	4
Bank holiday weekend	0
Road Surface	
Dry	3
Wet	7
Other/Unknown	1
Junction	
Yes	1
No	10
Speed Limit	
$\leq$ 60 km/h	0
80km/h	3
100km/h	8
120km/h	0
Injuries	
Fatal	1
Serious	2
Minor	12
Not Injured/Unknown	0

The N78 national secondary road runs from M9 junction 3 - N78/N77 intersection, north of Kilkenny, Co. Kilkenny. Originally the N78 (before the opening of the M9 Kilcullen-Carlow in 2010) ran from M9/N9 intersection Kilcullen, Co. Kildare to N78/N77 intersection, north of Kilkenny, Co. Kilkenny. The section of road originally called the N78 which ran from M9/N9 intersection, Kilcullen, Co. Kildare to R418 intersection east of Athy, Co. Kildare has now been downgraded to a regional road to the R418. Seventy four road traffic collisions were recorded on the N78 road from 2005-2009. The scan statistic was run on 71 road traffic collisions. Collisions with geographical coordinates located more than 100m from the N78 road were excluded from the analysis. One cluster was identified and Table 47 gives detailed description of this cluster. A geographical representation of the cluster can be seen in the map: N78 hot spots and corridors.

- **Cluster 1**
  - Location: Duke Street, Athy, Co. Kildare - South West of Kilmeade, Co. Kildare
  - Number of collisions: 21
  - Length: 6.9km

Approximately 57.1% (12/21) of the collisions recorded in cluster 1 were multi-vehicle involved collisions, 33.3% (7/21) were pedestrian involved collisions, 95.2% (20/21) occurred during the hours of darkness and 76.2% (16/21) occurred on a weekday. Approximately 57.1% (12/21) occurred on a dry road surface, 33.3% (7/21) occurred at a junction and 52.4% (11/21) occurred on sections of road with speed limits 60km/h or less. Thirty three injuries sustained were minor injuries, zero serious injuries and zero fatalities were recorded in this cluster.

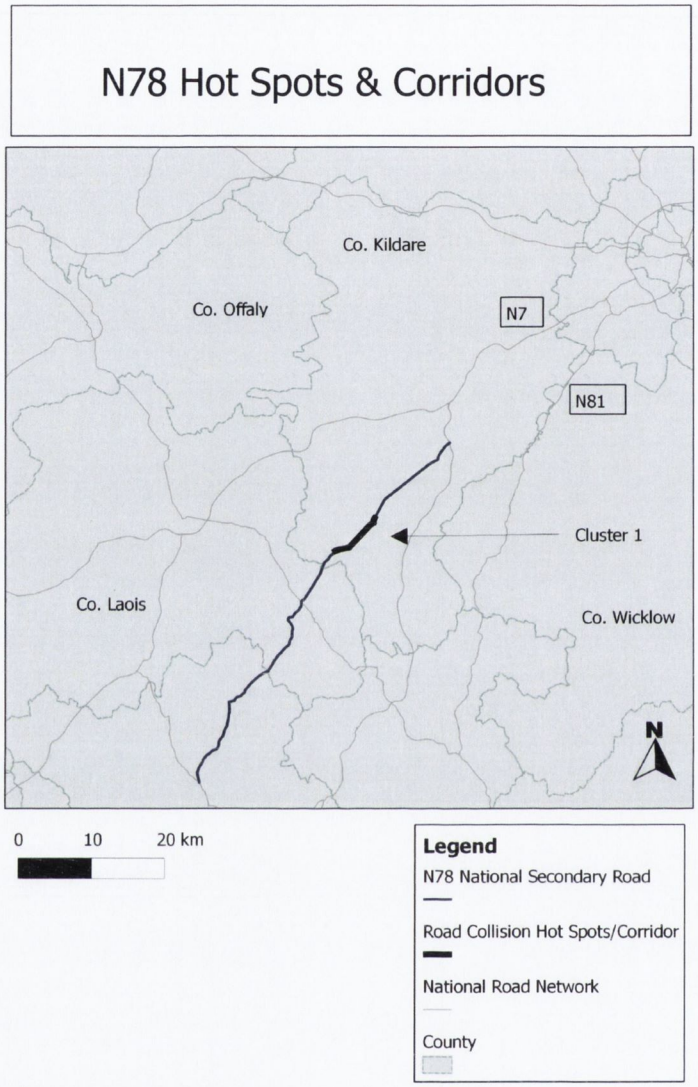


Figure 37: N78 Collision Hot Spots/Corridors

Table 47: N78 Road Collision Hot Spots/Corridors

Description	Cluster 1
Number of Collisions	21
Collision Type	
Pedestrian	7
Single Vehicle	0
Head-on	4
Angle	1
Rear-end	7
Unknown	2
Light	
Hours of daylight	0
Hours of darkness	20
Unknown	1
Day	
Weekday	16
Weekend	5
Bank holiday weekend	0
Road Surface	
Dry	12
Wet	6
Other/Unknown	3
Junction	
Yes	7
No	14
Speed Limit	
$\leq$ 60 km/h	11
80km/h	1
100km/h	9
120km/h	0
Injuries	
Fatal	0
Serious	0
Minor	33
Not Injured/Unknown	1

The N80 national secondary road runs from N80/N11 intersection, north of Enniscorthy, Co. Wexford to N80/N52 intersection, Tullamore, Co. Offaly. One hundred and sixty eight road traffic collisions were recorded on the N80 road from 2005-2009. The scan statistic was run on 160 road traffic collisions. Collisions with geographical coordinates located more than 100m from the N80 road were excluded from the analysis. Three clusters were identified and Table 48 gives detailed description of each cluster. A geographical representation of the cluster can be seen in the map: N80 hot spots and corridors.

- **Cluster 1**
  - Location: R745/N80 intersection, Co. Wexford
  - Number of collisions: 6
  - Length: 15m

Approximately 33.3% (2/6) of the collisions recorded in cluster 1 were multi-vehicle involved collisions, 83.3% (5/6) occurred during the hours of darkness and 66.7% (4/6) occurred on a weekday. Approximately 66.7% (4/6) occurred on a dry road surface, all occurred at a junction and all occurred on sections of road with speed limits 100km/h. Ten injuries sustained were minor injuries, two serious injuries and one fatality were recorded in this cluster.

- **Cluster 2**
  - Location: Tullow Road, Carlow, Co. Carlow - Wexford Road Carlow, Co. Carlow
  - Number of collisions: 13
  - Length: 1.3km

Approximately 76.9% (10/13) of the collisions recorded in cluster 2 were multi-vehicle involved collisions, 92.3% (12/13) occurred during the hours of darkness and 61.5% (8/13) occurred on a weekday. Approximately 53.8% (7/13) occurred on a dry road surface, 23.1% (3/13) occurred at a junction and 84.6% (11/13) occurred on sections of road with speed limits 60km/h or less. Fifteen injuries sustained were minor injuries, two serious injuries and two fatalities were recorded in this cluster.

- **Cluster 3**
  - Location: Derrybeg (Geashill By), Co. Offaly - South of Derrybeg, (Geashill By), Co. Offaly

- Number of collisions: 8
- Length: 796m

Approximately 75% (6/8) of the collisions recorded in cluster 3 were multi-vehicle involved collisions, 87.5% (7/8) occurred during the hours of darkness and 75% (6/8) occurred on a weekday. Approximately 37.5% (3/8) occurred on a dry road surface, 12.5% (1/8) occurred at a junction and 75% (6/8) occurred on sections of road with speed limits 100km/h. Seven injuries sustained were minor injuries, three serious injuries and one fatality were recorded in this cluster.

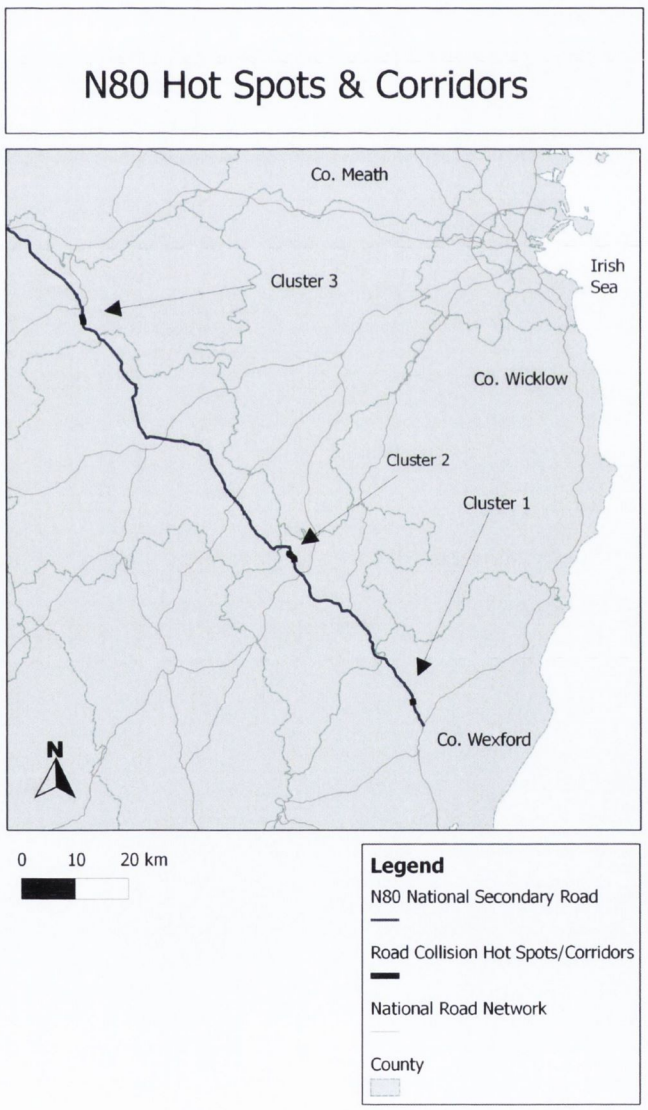


Figure 38: N80 Collision Hot Spots/Corridors

Table 48: N80 Road Collision Hot Spots/Corridors

Description	Cluster 1	Cluster 2	Cluster 3
Number of Collisions	6	13	8
Collision Type			
Pedestrian	0	3	0
Single Vehicle	0	1	1
Head-on	0	3	2
Angle	1	2	2
Rear-end	1	2	2
Unknown	4	2	1
Light			
Hours of daylight	1	1	1
Hours of darkness	5	12	7
Unknown	0	0	0
Day			
Weekday	4	8	6
Weekend	1	4	2
Bank holiday weekend	1	1	0
Road Surface			
Dry	4	7	3
Wet	2	6	5
Other/Unknown	0	0	0
Junction			
Yes	6	3	1
No	0	10	7
Speed Limit			
$\leq$ 60 km/h	0	11	0
80km/h	0	1	2
100km/h	6	1	6
120km/h	0	0	0
Injuries			
Fatal	1	2	1
Serious	2	2	3
Minor	10	15	7
Not Injured/Unknown	1	0	0

The N83 national secondary road runs from N83/N17 intersection at Tuam, Co. Galway to N83/N17 intersection at Glentavraun Co. Mayo. For the purposes of this analysis, the N83 was split into sections. Section 1 runs from N83/N17 intersection at Tuam, Co. Galway to N83/N60 intersection at Ballyhaunis, Co. Mayo and section 2 runs from Ballyhaunis, Co. Mayo to N83/N17 intersection at Glentavraun Co. Mayo. Twenty one road traffic collisions were recorded on the N83 road from 2005-2009. The scan statistic was run on 20 road traffic collisions (all in section 1). Collisions with geographical coordinates located more than 100m from the N83 road were excluded from the analysis. One cluster was identified in section 1 and Table 49 gives detailed description of this cluster. A geographical representation of the cluster can be seen in the map: N83 hot spots and corridors.

- **Section 1: Cluster 1**
  - Location: Cloonfad, Co. Roscommon - Riverbank/N83 intersection, Cloonfad, Co. Roscommon
  - Number of collisions: 5
  - Length: 799m

Approximately 20% (1/5) of the collisions recorded in cluster 1 were multi-vehicle involved collisions, 40% (2/5) were pedestrian involved collisions, all occurred during the hours of darkness and 60% (3/5) occurred on a weekday. Approximately 60% (3/5) occurred on a dry road surface, 40% (2/5) occurred at a junction and 80% (4/5) occurred on sections of road with speed limits 60km/h or less. Six injuries sustained were minor injuries, two serious injuries and zero fatalities were recorded in this cluster.

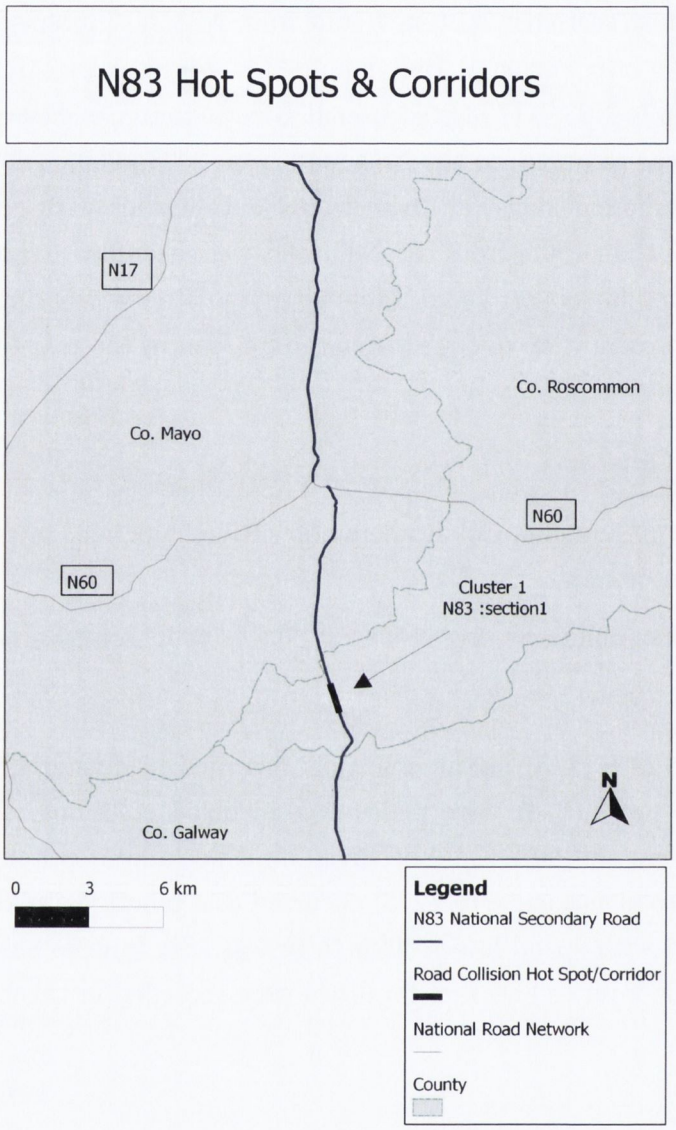


Figure 39: N83 Collision Hot Spots/Corridors

Table 49: N83 Section 1 Road Collision Hot Spots/Corridors

Description	Cluster 1
Number of Collisions	5
Collision Type	
Pedestrian	1
Single Vehicle	2
Head-on	0
Angle	1
Rear-end	0
Unknown	1
Light	
Hours of daylight	0
Hours of darkness	5
Unknown	0
Day	
Weekday	3
Weekend	2
Bank holiday weekend	0
Road Surface	
Dry	3
Wet	1
Other/Unknown	1
Junction	
Yes	2
No	3
Speed Limit	
$\leq$ 60 km/h	4
80km/h	1
100km/h	0
120km/h	0
Injuries	
Fatal	0
Serious	2
Minor	6
Not Injured/Unknown	2

The N84 national secondary road runs from Galway City, Co. Galway to Castlebar, Co. Mayo. Fifty road traffic collisions were recorded on the N84 road from 2005-2009. The scan statistic was run on 20 road traffic collisions. Collisions with geographical coordinates located more than 100m from the N84 road were excluded from the analysis. One cluster was identified in section 1 and Table 50 gives detailed description of this cluster. A geographical representation of the cluster can be seen in the map: N84 hot spots and corridors.

- **Cluster 1**
  - Location: South of Carrowbrowne, Co. Galway - Ballinfoyle, Co. Galway
  - Number of collisions: 18
  - Length: 4.4km

Approximately 38.9% (7/18) of the collisions recorded in cluster 1 were multi-vehicle collisions, 22.2% (4/18) were single vehicle collisions, 77.8% (14/18) occurred during the hours of darkness and 61.1% (11/18) occurred on a weekday. Approximately 55.6% (10/18) occurred on a dry road surface, 38.9% (7/18) occurred at a junction and 61.1% (11/18) occurred on sections of road with speed limits 100km/h. Twenty injuries sustained were minor injuries, two serious injuries and one fatality were recorded in this cluster.

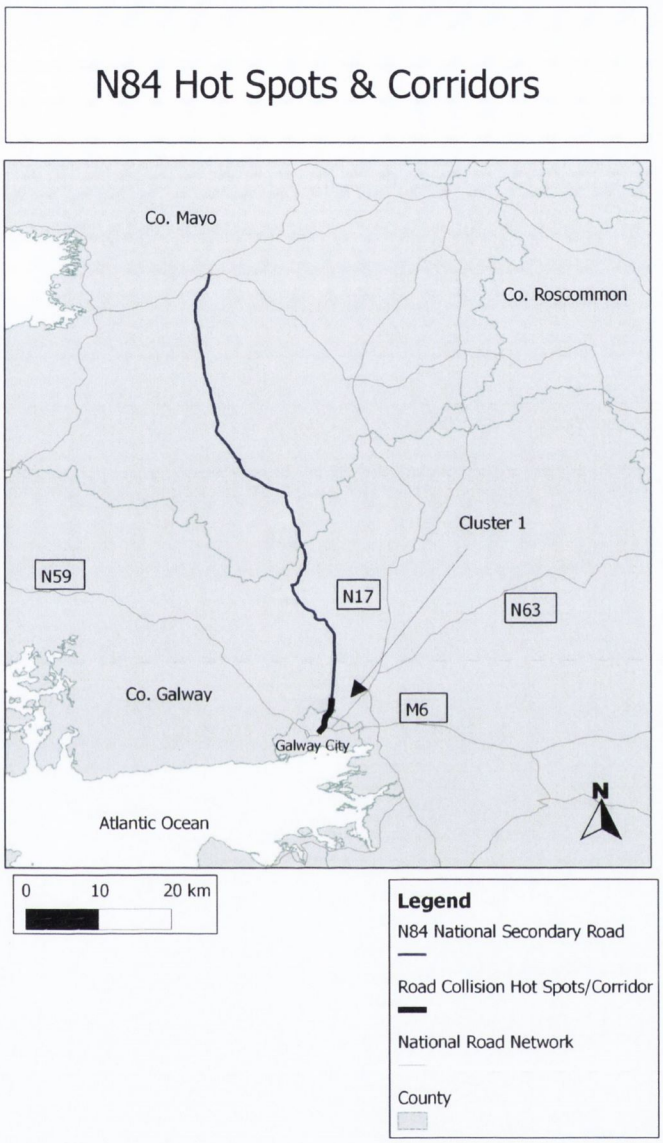


Figure 40: N84 Collision Hot Spots/Corridors

Table 50: N84 Road Collision Hot Spots/Corridors

Description	Cluster 1
Number of Collisions	18
Collision Type	
Pedestrian	1
Single Vehicle	4
Head-on	3
Angle	2
Rear-end	2
Unknown	6
Light	
Hours of daylight	4
Hours of darkness	14
Unknown	0
Day	
Weekday	11
Weekend	7
Bank holiday weekend	0
Road Surface	
Dry	10
Wet	8
Other/Unknown	0
Junction	
Yes	7
No	11
Speed Limit	
$\leq$ 60 km/h	6
80km/h	1
100km/h	11
120km/h	0
Injuries	
Fatal	1
Serious	2
Minor	20
Not Injured/Unknown	0

.9 Collision Hot Spots/Corridors: Geo-coordinates

National Primary Roads

Route	Approximate Location (From)
N10 (1)	Floodhall, Co. Kilkenny
N10 (2)	Ring Road, Kilkenny, Co. Kilkenny
N11 (1)	Leinster Street/Kildare Street intersection, Dublin City
N11 (2)	North of Jack White's Cross Roads, Co. Wicklow
N11 (3)	South of Ballinameesda Upper, Co. Wicklow
N15 (1)	Bundoran Road, Sligo, Co. Sligo
N15 (2)	Donegal Road/Pettigoe Road intersection, Laghy, Co. Donegal
N17 (1)	R331(Ballindine Rd)/N17 intersection, Co. Mayo
N17 (2)	N17/N63 intersection, Co. Galway
N2 (1)	N2/Upper Dorset Street intersection, Dublin City
N2 (2)	R150/N2 intersection, Flemington, Co. Meath
N2 (3)	North Road, (North east of Coolfore) Co. Meath
N2 (4)	Mullynure, Co. Monaghan
N20 (1)	R518/N20 Intersection, Limerick, Co. Limerick
N20 (2)	Commons Road, Cork, Co. Cork
N20 (3)	Limerick Road, Charleville, Co. Cork
N20 (4)	Southill, Limerick, Co. Limerick
N22 (1)	Lissivigeen, Co. Kerry
N22 (2)	N22/Washington St intersection, Cork, Co. Cork
N22 (3)	North of N22/R561 intersection, Farranfore, Co. Kerry
N25 (1)	East of Ballyedekin, Co. Cork
N25 (2)	N30/N25 intersection, New Ross, Co. Wexford
N25 (3)	West of Larkins Cross, Co. Wexford
N3 (1)	NorthWest of Blackbull, Co. Meath (M3)
N3 (2)	Main Street Dunsaughlin, Co. Meath
N3 (3)	Dublin Road, Co. Cavan
N3 (4)	South of Ross (Ed Tara), Co. Meath
N3 (5)	North Circular Rd/Phibsborogh Rd intersection, Dublin City
N4 (1)	Aston Quay/Westmoreland Street intersection, Dublin City
N4 (2)	Ballymahon Road, Edgeworthstown, Co. Longford
N5 (1)	Bridge Street, Westport, Co. Mayo
N6 (1)	Headford Road, Galway, Co. Galway
N6 (2)	Dublin Road, Co. Westmeath
N6 (3)	South west of Toberiheen, Co. Roscommon (Now called R446 road)
N7 (1)	Newlands Cross, Co. Dublin
N7 (2)	Dublin Road, Co. Limerick
N7 (3)	West of Newlands Cross, Co. Dublin
N8 (1)	North East of Richmond, Co. Cork
N8 (2)	South of Corbally, Co. Laois

( ) denote labels for individual hot spots/corridors

National Primary Roads

Route	N (from)	W (from)	Height
N10 (1)	N 52 30 48.316	W 07 12 52.445	56.107
N10 (2)	N 52 38 14.781	W 07 14 14.505	56.051
N11 (1)	N 53 20 31.820	W 06 15 16.417	56.09
N11 (2)	N 52 52 57.900	W 06 05 55.366	56.088
N11 (3)	N 52 56 7.983	W 06 07 21.665	56.145
N15 (1)	N 54 16 44.594	W 08 28 24.364	57.744
N15 (2)	N 54 37 8.534	W 08 05 17.456	57.625
N17 (1)	N 53 42 31.197	W 08 59 3.382	57.85
N17 (2)	N 53 21 43.239	W 08 55 36.104	57.551
N2 (1)	N 53 21 15.213	W 06 16 0.732	56.116
N2 (2)	N 53 38 25.641	W 06 29 56.882	56.326
N2 (3)	N 53 33 8.777	W 06 26 9.094	56.284
N2 (4)	N 54 23 56.525	W 06 58 31.743	57.255
N20 (1)	N 52 25 38.608	W 08 41 27.821	57.485
N20 (2)	N 51 55 10.195	W 08 28 53.704	57.096
N20 (3)	N 52 21 25.380	W 08 41 5.439	57.485
N20 (4)	N 52 39 5.392	W 08 38 9.282	57.362
N22 (1)	N 52 03 18.470	W 09 27 50.279	58.042
N22 (2)	N 51 53 51.222	W 08 28 44.975	57.085
N22 (3)	N 52 10 17.636	W 09 33 1.230	58.156
N25 (1)	N 51 54 53.583	W 08 06 41.491	56.76
N25 (2)	N 52 23 10.201	W 06 55 32.351	56.294
N25 (3)	N 52 20 23.861	W 06 33 53.954	56.191
N3 (1)	N 53 27 1.297	W 06 28 43.256	56.313
N3 (2)	N 53 30 28.302	W 06 32 24.005	56.339
N3 (3)	N 53 59 2.875	W 07 20 7.031	57.026
N3 (4)	N 53 33 57.263	W 06 34 46.099	56.351
N3 (5)	N 53 21 38.787	W 06 16 21.496	56.128
N4 (1)	N 53 20 49.027	W 06 15 33.220	56.1
N4 (2)	N 53 41 37.142	W 07 36 43.123	56.87
N5 (1)	N 53 47 58.263	W 09 31 19.722	58.21
N6 (1)	N 53 17 9.834	W 09 02 44.705	57.403
N6 (2)	N 53 24 2.884	W 07 52 17.331	56.783
N6 (3)	N 53 20 50.108	W 08 05 21.076	56.93
N7 (1)	N 53 18 47.081	W 06 23 24.621	56.19
N7 (2)	N 52 42 46.156	W 08 29 18.502	57.279
N7 (3)	N 53 18 45.717	W 06 23 32.671	56.191
N8 (1)	N 51 54 30.882	W 08 23 1.069	56.985
N8 (2)	N 52 56 18.285	W 07 20 58.549	56.365

National Primary Roads

Route	Approximate Location (To)
N10 (1)	South of Flood Hall, Co. Kilkenny
N10 (2)	Ring Road Kilkenny, Co. Kilkenny
N11 (1)	Dublin Road, Dublin 18 (near Seaview Wood roundabout)
N11 (2)	Jack White Cross Roads, Co. Wicklow
N11 (3)	Barndarrig, Co. Wicklow
N15 (1)	Bundoran Road, Co. Donegal
N15 (2)	South of Laghy, Co. Donegal
N17 (1)	South of Ballindine Rd intersection, Co. Mayo
N17 (2)	South West of Laghtgeorge, Co. Galway
N2 (1)	N2 (North Road), Dublin 11
N2 (2)	N2/R150 intersection, Flemington, Co. Meath
N2 (3)	Cushinstown, (Ed Kilbrew), Co. Meath
N2 (4)	Mullynure, Co. Monaghan
N20 (1)	O'Rourke's Cross, Co. Limerick
N20 (2)	North Ring road, Cork, Co. Cork
N20 (3)	Main Street Charleville, Co. Cork
N20 (4)	Childers Road, Limerick, Co. Limerick
N22 (1)	N72,N22 Intersection, Lissivigeen, Co. Kerry
N22 (2)	St. Patricks St. Cork, Co. Cork
N22 (3)	Intersection R561, N22, Farranfore, Co. Kerry
N25 (1)	Bandon Road Roundabout, Cork, Co. Cork
N25 (2)	South West of N30/N25 intersection, Co. Wexford
N25 (3)	Wset of Larkins Cross, Co. Wexford
N3 (1)	North West of Black Bull, Co. Meath
N3 (2)	North West of Cooksland, Co. Meath
N3 (3)	South East of Annagelliff, Co. Cavan
N3 (4)	South of Ross (Ed Tara), Co. Meath
N3 (5)	Navan Road North West of Nephin Road intersection. (near Pope John Paul II park), Co. Dublin
N4 (1)	Leixlip Road, North West of Celbridge Road Interchange, Co. Dublin
N4 (2)	Noth West of Ballymahon Rd, Co. Longford
N5 (1)	West of Cloggernagh East, Co. Mayo
N6 (1)	Dun Na Coiribe, West of Bodkin Roundabout, Galway, Co. Galway
N6 (2)	Athlone bypass, Co. Westmeath
N6 (3)	South West of BallyDangan Co. Roscommon
N7 (1)	Newlands Cross, Co. Dublin
N7 (2)	South West of Daly's Cross, Castleconnell, Co. Limerick
N7 (3)	Naas Dual Carriage Way, Naas Co. Kildare
N8 (1)	St. Patricks St Bridge, Co. Cork
N8 (2)	Main Street, Abbeyleix, Co. Laois (Now Named N77)

( ) denote labels for individual hot spots/corridors

National Primary Roads

Route	N (To)	W (To)	Height
N10 (1)	N 52 30 45.784	W 07 12 52.858	56.108
N10 (2)	N 52 38 11.320	W 07 14 25.352	56.054
N11 (1)	N 53 14 28.164	W 06 07 42.365	55.935
N11 (2)	N 52 52 57.806	W 06 05 56.254	56.088
N11 (3)	N 52 54 35.222	W 06 06 31.061	56.112
N15 (1)	N 54 16 42.845	W 08 28 27.127	57.55
N15 (2)	N 54 37 7.947	W 08 05 18.106	57.625
N17 (1)	N 53 42 25.364	W 08 59 0.248	57.848
N17 (2)	N 53 21 16.051	W 08 56 0.325	57.539
N2 (1)	N 53 24 12.003	W 06 18 39.452	56.204
N2 (2)	N 53 38 26.214	W 06 29 57.839	56.326
N2 (3)	N 53 34 27.140	W 06 27 3.932	56.284
N2 (4)	N 54 23 58.741	W 06 58 32.002	56.753
N20 (1)	N 52 25 38.585	W 08 41 27.083	57.485
N20 (2)	N 51 54 34.178	W 08 28 22.766	57.082
N20 (3)	N 52 21 19.572	W 08 41 1.389	57.484
N20 (4)	N 52 38 53.476	W 08 37 44.762	57.355
N22 (1)	N 52 03 2.472	W 09 27 26.299	58.04
N22 (2)	N 51 54 0.471	W 08 28 13.927	57.076
N22 (3)	N 52 10 13.987	W 09 32 59.226	58.156
N25 (1)	N 51 52 28.098	W 08 31 21.329	57.147
N25 (2)	N 52 23 08.954	W 06 55 33.582	56.294
N25 (3)	N 52 20 23.885	W 06 33 53.254	56.19
N3 (1)	N 53 27 5.315	W 06 28 50.301	56.315
N3 (2)	N 53 31 12.980	W 06 32 58.280	56.34
N3 (3)	N 53 59 4.074	W 07 20 13.739	57.027
N3 (4)	N 53 34 1.761	W 06 34 47.158	56.351
N3 (5)	N 53 21 57.084	W 06 18 39.264	56.167
N4 (1)	N 53 21 22.181	W 06 27 42.112	56.242
N4 (2)	N 53 41 50.349	W 07 37 35.153	56.888
N5 (1)	N 53 49 13.983	W 09 22 49.799	58.17
N6 (1)	N 53 16 56.482	W 09 02 55.122	57.396
N6 (2)	N 53 25 52.513	W 07 57 25.258	56.866
N6 (3)	N 53 20 28.670	W 08 06 12.693	56.94
N7 (1)	N 53 18 45.877	W 06 23 25.203	56.19
N7 (2)	N 52 42 28.909	W 08 29 29.529	57.278
N7 (3)	N 53 14 11.087	W 06 40 45.662	56.25
N8 (1)	N 51 54 3.445	W 08 28 13.017	57.076
N8 (2)	N 52 54 46.193	W 07 20 58.039	56.349

National Secondary Roads

Route	Approximate Location (From)
N52P1 (1)	South of Durrow Demense, Co. Offaly
N52P1 (1)	South of Durrow Demense, Co. Offaly
N52P4 (1)	Dundalk bypass, Barrack Street intersection, Dundalk Co. Louth
N52P4 (2)	Eastern bypass road roundabout, Co. Louth
N54P1 (1)	Cavan Road, Co. Cavan Just south of the Northern Ireland border
N55P2 (1)	North East of Cranalagh More, Co. Longford
N56 (1)	North West of Knocknabollan, Co. Donegal
N56 (2)	West of Mountcharles, Co. Donegal
N59P1 (1)	Quay Street, Westport, Co. Mayo
N59P2 (1)	Sligo Road, Ballina, Co. Mayo
N59P2 (2)	Newport Road Intersection with the Paddock, Westport, Co. Mayo
N61 (1)	Near Casheltauna, Co. Roscommon
N67P2 (1)	N67/Glenveil Road intersection, Co. Clare
N69 (1)	R521 (Askeaton Rd) / N69 Intersection, Co. Limerick
N69 (2)	Glenameade Road, Co. Limerick
N69 (3)	Clarina, Co. Limerick
N71P1 (1)	Churraigh, Co. Cork
N72P2 (1)	R579/N72 Intersection, Ballyquirk, Co. Cork
N72P2 (2)	West of The fair field, Dromagh, Co. Cork
N76 (1)	Rathaleek, Co. Kilkenny
N77 (1)	Suttonsrath, Co. Kilkenny
N78 (1)	Duke Street, Athy, Co. Kildare
N80 (1)	R745/N80 intersection, Co. Wexford
N80 (2)	Tullow Road, Carlow, Co. Carlow
N80 (3)	Derrybeg (Geashill By), Co. Offaly
N81 (2)	Baltinglass Road, intersection with Naas Road, Blessington, Co. Wicklow
N83P1 (1)	Cloonfad, Co. Roscommon
N84P1 (1)	South of Carrowbrowne, Co. Galway

( ) denotes road traffic collision hot spot/corridor label

National Secondary Roads

Route	N (From)	W (From)	Height
N52P1 (1)	N 53 18 47.967	W 07 30 19.364	56.537
N52P1 (1)	N 53 18 47.967	W 07 30 19.364	56.537
N52P4 (1)	N 54 00 20.599	W 06 23 12.397	56.816
N52P4 (2)	N 53 58 13.327	W 06 25 21.081	56.738
N54P1 (1)	N 54 06 56.200	W 07 20 45.670	57.175
N55P2 (1)	N 53 42 48.672	W 07 34 54.344	56.868
N56 (1)	N 55 03 8.278	W 07 49 18.109	57.467
N56 (2)	N 54 39 0.038	W 08 12 30.422	57.68
N59P1 (1)	N 53 47 52.965	W 09 31 45.895	58.212
N59P2 (1)	N 54 07 15.600	W 09 07 51.601	58.117
N59P2 (2)	N 53 48 11.418	W 09 31 14.185	58.209
N61 (1)	N 53 42 54.062	W 08 12 31.696	57.446
N67P2 (1)	N 52 54 39.961	W 09 20 44.836	58.022
N69 (1)	N 52 35 41.729	W 09 05 19.777	57.94
N69 (2)	N 52 37 40.162	W 08 50 28.555	57.613
N69 (3)	N 52 37 56.112	W 08 43 58.746	57.465
N71P1 (1)	N 51 36 48.712	W 08 56 54.835	57.701
N72P2 (1)	N 52 08 19.129	W 08 54 11.575	57.689
N72P2 (2)	N 52 07 29.432	W 08 58 44.099	57.798
N76 (1)	N 52 36 50.338	W 07 17 19.168	56.093
N77 (1)	N 52 43 16.689	W 07 17 51.787	56.13
N78 (1)	N 52 59 29.075	W 06 59 18.140	56.04
N80 (1)	N 52 34 56.822	W 06 34 41.869	56.173
N80 (2)	N 52 50 4.104	W 06 54 47.478	55.8
N80 (3)	N 53 14 13.075	W 07 28 42.830	56.513
N81 (2)	N 53 10 7.905	W 06 32 6.527	56.29
N83P1 (1)	N 53 40 50.361	W 08 44 54.211	57.649
N84P1 (1)	N 53 19 29.045	W 09 01 17.146	57.476

National Secondary Roads

Route	Approximate Location (To)
N52P1 (1)	Main Street, Athboy, Co. Meath
N52P1 (1)	North of Durrow Demense, Co. Offaly
N52P4 (1)	Dundalk bypass/Barrack St intersection, Dundalk, Co. Louth
N52P4 (2)	Eastern bypass Road, Co. Louth
N54P1 (1)	Gannons Cross, Co. Cavan
N55P2 (1)	North East of Cranalagh More, Co. Longford
N56 (1)	Letterkenny, Co. Donegal
N56 (2)	North West of Turrishill, Co. Donegal
N59P1 (1)	Newport St, Westport, Co. Mayo
N59P2 (1)	Dillon Terrace, Balina, Co. Mayo
N59P2 (2)	North Mall/Newport Street Intersection, Westport, Co. Mayo
N61 (1)	Athlone Road, Roscommon, Co. Roscommon
N67P2 (1)	Ballycarraeile, Co. Clare
N69 (1)	R521(Askeaton Road)/N69 intersection, Co. Limerick
N69 (2)	West of Coolbeg, Co. Limerick
N69 (3)	N69/Ballybrown (Ed Clarina) intersection, Co. Limerick
N71P1 (1)	Hawkes Road, Cork, Co. Cork
N72P2 (1)	R579/N72 Intersection, Co. Cork
N72P2 (2)	The Fair Field, Co. Cork
N76 (1)	Callan Road, Co. Kilkenny
N77 (1)	Castlecomer Road Co. Kilkenny
N78 (1)	South West of Kilmeade, Co. Kildare
N80 (1)	R745/N80 Intersection, Co. Wexford
N80 (2)	Wexford Road Carlow, Co. Carlow
N80 (3)	South of Derrybeg, (Geashill By), Co. Offaly
N81 (2)	Main Street Blessington, Co. Wicklow
N83P1 (1)	Riverbank/N83 intersection, Cloonfad, Co. Roscommom
N84P1 (1)	Ballinfoyle, Co. Galway

( ) denotes road traffic collision hot spot/corridor label

National Secondary Roads

Route	N (To)	W (To)	Height
N52P1 (1)	N 53 37 21.660	W 06 55 7.578	56.552
N52P1 (1)	N 53 19 26.875	W 07 30 42.137	56.545
N52P4 (1)	N 54 00 20.771	W 06 23 12.866	56.816
N52P4 (2)	N 53 58 15.560	W 06 25 11.985	56.746
N54P1 (1)	N 54 06 0.792	W 07 21 57.797	57.163
N55P2 (1)	N 53 42 53.266	W 07 34 48.547	56.868
N56 (1)	N 54 58 45.885	W 07 43 35.287	57.497
N56 (2)	N 54 38 59.558	W 08 13 10.649	57.684
N59P1 (1)	N 53 48 9.863	W 09 31 14.235	58.209
N59P2 (1)	N 54 06 53.806	W 09 09 1.283	58.12
N59P2 (2)	N 53 48 4.035	W 09 31 19.990	58.209
N61 (1)	N 53 37 29.833	W 08 10 23.796	57.307
N67P2 (1)	N 52 59 8.031	W 09 18 0.302	57.883
N69 (1)	N 52 35 41.082	W 09 05 19.259	57.94
N69 (2)	N 52 37 23.431	W 08 48 58.989	57.576
N69 (3)	N 52 37 58.298	W 08 43 42.424	57.46
N71P1 (1)	N 51 52 38.905	W 08 31 21.709	57.144
N72P2 (1)	N 52 08 19.105	W 08 54 11.776	57.69
N72P2 (2)	N 52 07 28.482	W 08 58 32.892	57.794
N76 (1)	N 52 37 15.097	W 07 16 55.920	56.084
N77 (1)	N 52 41 36.742	W 07 15 37.086	56.083
N78 (1)	N 53 01 40.805	W 06 54 43.784	56.054
N80 (1)	N 52 34 56.784	W 06 34 42.117	56.173
N80 (2)	N 52 49 32.067	W 06 53 53.295	55.783
N80 (3)	N 53 13 48.472	W 07 28 31.886	56.513
N81 (2)	N 53 10 15.388	W 06 31 56.749	56.292
N83P1 (1)	N 53 41 14.669	W 08 45 8.283	57.656
N84P1 (1)	N 53 17 21.239	W 09 02 34.806	57.409

Regional Roads

Route	Approximate Location (From)
R402	St. Mary's Rd, Edenderry, Co. Offaly
R423	South West of Esker, Co. Laois

Route	N (From)	W (From)	Height
R402	N 53 20 5.784	W 07 03 51.246	56.373
R423	N 53 04 39.897	W 07 23 31.810	56.479

Route	Approximate Location (To)
R402	Dublin Rd, Edenderry, Co. Offaly
R423	Clonygowan, Co. Laois

Route	N (To)	W (To)	Height
R402	N 53 20 40.101	W 07 02 36.136	56.373
R423	N 53 04 4.948	W 07 24 5.963	56.487

N81 Speed Zones

Zone	Approximate Location (From)
1(1)	New street south/R110 intersection, Dublin 8
2(1)	R136 (Cheeverstown Rd)/N81(Tallaght Pass) intersection
3(1)	South of Ballylion Lower, Co. Wicklow
3(2)	North of R756 intersection, Knockroe, Co. Wicklow

Zone	N (From)	W (From)	Height
1(1)	N 53 20 19.350	W 06 16 20.921	56.105
2(1)	N 53 16 53.631	W 06 23 17.249	56.214
3(1)	N53 00 34.244	W 06 38 31.053	56.114
3(2)	N 53 05 31.201	W 06 36 25.201	56.187

Zone	Approximate Location (To)
1(1)	New street south/R110 intersection, Dublin 8
2(1)	N81/R136 intersection, South Co. Dublin
3(1)	Whitestown Upper, Co. Wicklow
3(2)	R756/N81 intersection, Co. Wicklow

Zone	N (To)	W (To)	Height
1(1)	N 53 20 19.973	W 06 16 20.492	56.105
2(1)	N 53 16 53.629	W 06 23 17.727	56.214
3(1)	N 52 59 47.022	W 06 38 52.516	56.092
3(2)	N 53 05 28.235	W 06 36 24.797	56.204

.10 Bayesian Model Code

```
#####################################################################
## Logistic Model
#####################################################################
## JAGS CODE (see below)
##
## Dependent (response) variable: y = Fatal/serious injuries;
## x1, x2,.....,x11 denote independent variables
## N = total number of persons involved in the collision,
## Note: This is a special case of the binomial where N=1
##
## Data used to develop this model: single vehicle `driver only' collision
##data (2004-2008)
#####################################################################

library(R2jags) ## Load package into R
Data<-read.table(file.choose(),header=T)  ## Load Data into R
attach(Data)
names(Data)

y<-FatalSerious.versus.Minor_Injuries
x1<-factor(Light)  ## Define independent variables as factors in R
x2<-factor(Weekend)
x4<-factor(Road_Surface)
x6<-factor(Collision_Type)
x7<-factor(Speed_Limit)
x9<-factor(Vehicle_Type)
x10<-factor(Road_Characteristics)
x11<-factor(Sex_of_Driver)
N<-1
nn<-nrow(Data)

#########################################################
## number of levels for independent  variables
#########################################################
ngrp2=2 #variables with 2 levels
ngrp3=3 #variables with 3 levels
ngrp4=4 #variables with 4 levels
ngrp5=5 #variables with 5 levels
ngrp6=6 #variables with 6 levels

#########################################################
## working directory (when using Mac)
#########################################################
setwd("/users/erica/desktop") ### this is the path for the Mac computer

#################################################################
##Save BUGS description of the model to working directory
#################################################################

sink("Jags_SingVehDriverOnly_model9var_2004_2008.txt")
```

```
#########################################################################
## define Bugs model ####
#########################################################################

 cat("
  model {

############
## likelihood
############
for(i in 1:nn){
 y[i] ~ dbin(p[i],N)
 logit(p[i])<-alpha+beta.x1[x1[i]]+beta.x2[x2[i]] +beta.x4[x4[i]]+
beta.x6[x6[i]]+ beta.x7[x7[i]]+beta.x9[x9[i]]+ beta.x10[x10[i]]+
beta.x11[x11[i]]
 }

##############
## priors
############
 alpha~dnorm(0,0.001)
 beta.x1[1]<-0 # set variable group 1 as base group
 beta.x2[1]<-0
 beta.x4[1]<-0
 beta.x6[1]<-0
 beta.x7[1]<-0
 beta.x9[1]<-0
 beta.x10[1]<-0
 beta.x11[1]<-0

 for (q in 2:ngrp2){ #for variables with 2 levels
 beta.x11[q]~dnorm(0,0.001)
 }

 for (j in 2:ngrp3){ #for variables with 3 levels
 beta.x1[j]~dnorm(0,0.001)
 beta.x2[j]~dnorm(0,0.001)
  beta.x4[j]~dnorm(0,0.001)
 }

for (k in 2:ngrp4){ #for variables with 4 levels
beta.x10[k]~dnorm(0,0.001)
 }

 for (l in 2:ngrp5){ #for variables with 5 levels
beta.x6[l]~dnorm(0,0.001)
beta.x7[l]~dnorm(0,0.001)
beta.x9[l]~dnorm(0,0.001)
 }
 }
",fill=TRUE)
sink()
```

```
#########################################################################
## Parameters to estimate ####
#########################################################################
 m_params=c("alpha","beta.x1","beta.x2","beta.x4","beta.x6","beta.x7", "beta.x9",
"beta.x10","beta.x11")

#########################################################################
## Data used in JAGS ####
#########################################################################
 m_Data=list(nn=nn,y=y,N=N,x1=x1,x2=x2,x4=x4,x6=x6,x7=x7,x9=x9,x10=x10,x11=x11,
ngrp2=ngrp2,ngrp3=ngrp3,ngrp4=ngrp4,ngrp5=ngrp5)

#########################################################################
## MCMC settings ####
#########################################################################
 nc<-1 # No. of chains
 ni<-100000 # No. of iterations
 nb<-100 # No. of draws to discard as burn-in
 nt<-1 # Thinning rate



#########################################################################
## Run Model in JAGS ####
#########################################################################
 jags_sim=jags.model(file=
"Jags_SingVehDriverOnly_model9var_2004_2008.txt",data=m_Data, n.chains=nc)



#########################################################################
## Run MCMC ####
#########################################################################

outDriverOnly=coda.samples(model=jags_sim, m_params, n.iter=ni, thin=nt)
summary(outDriverOnly)



#########################################################################
##Package coda in R is used for diagnostic tests
## and package mcmcplots  is used to create caterpillar plots
#########################################################################

library(coda)
codamenu()

library(mcmcplots)
```

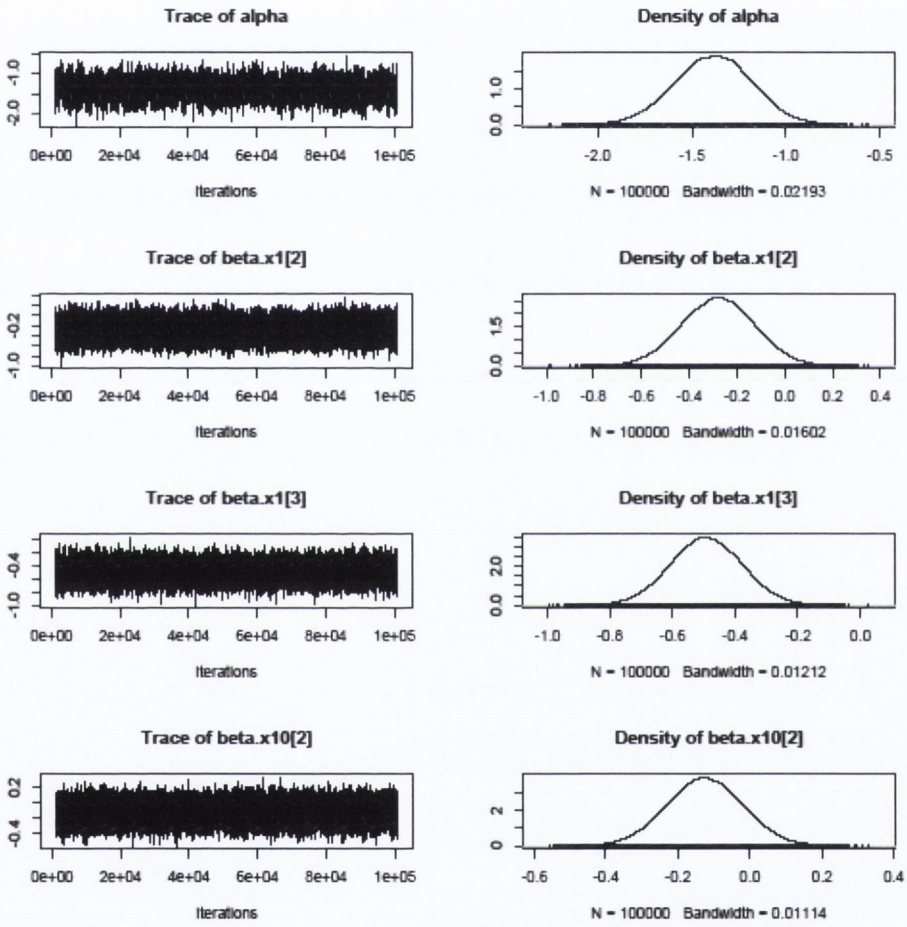
.11 Model Diagnostics

Table 51: Model Variables: Single Vehicle Driver-Only

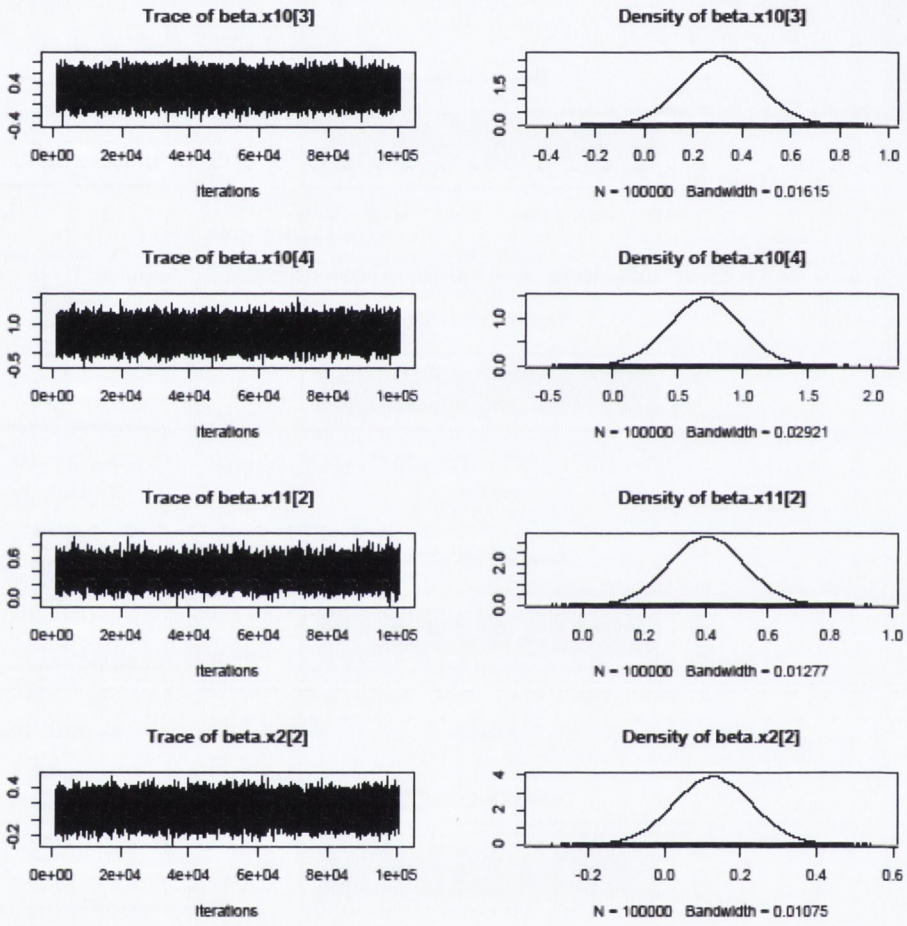
Variable	
x1[1]Baseline	**Daylight**
x1[2]	Dark with street lighting
x1[3]	Dark
x2[1]Baseline	**Week day**
x2[2]	Weekend
x2[3]	Public/Bank holiday weekend
x4[1]Baseline	**Dry road surface**
x4[2]	Wet road surface
x4[3]	Other road surface
x6[1]Baseline	**Collision with: object** e.g. wall/pole
x6[2]	Animal
x6[3]	Parked vehicle
x6[4]	Ditch
x6[5]	Other
x7[1]Baseline	**Speed limit: 50km/h**
x7[2]	60km/h
x7[3]	80km/h
x7[4]	100km/h
x7[5]	120km/h
x9[1] Baseline	**Vehicle Type: car**
x9[2]	Goods
x9[3]	Motorcycle
x9[4]	Public service vehicle e.g. bus
x9[5]	Other
x10[1]Baseline	**Road: straight**
x10[2]	bend
x10[3]	hill/gradient
x10[4]	other
x11[1]Baseline	**Female**
x11[2]	Male

.11.1 Single Vehicle - Driver Only

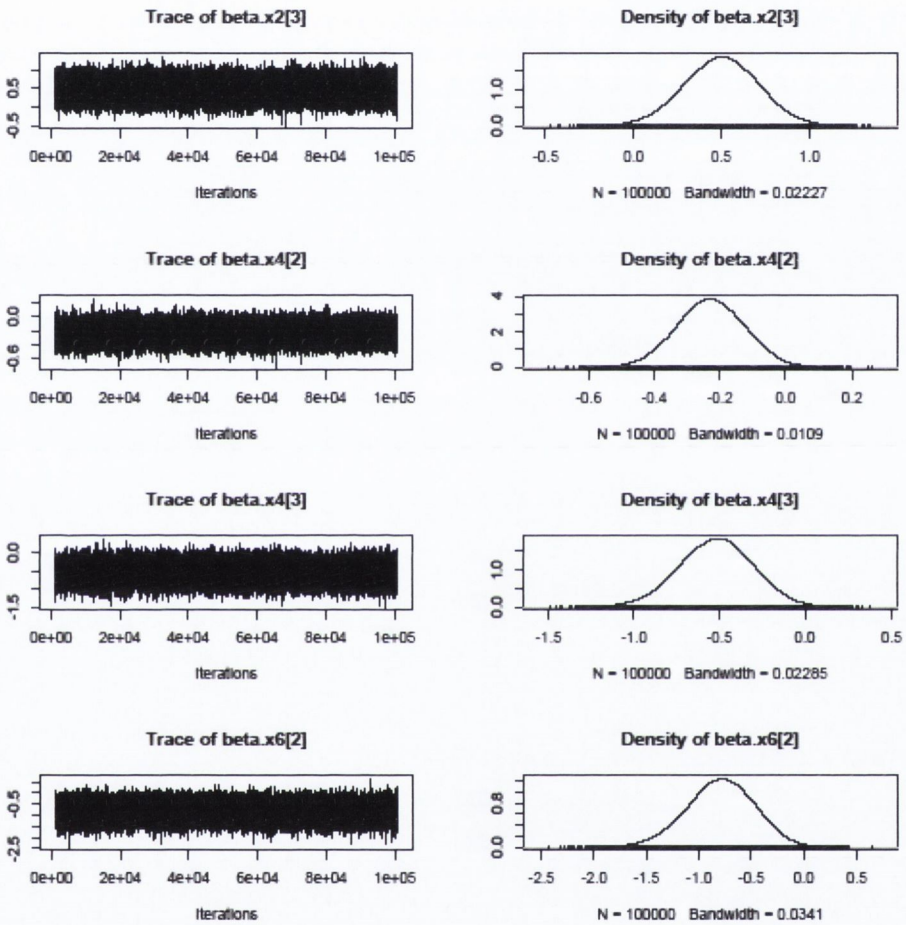
Trace and Density Plots



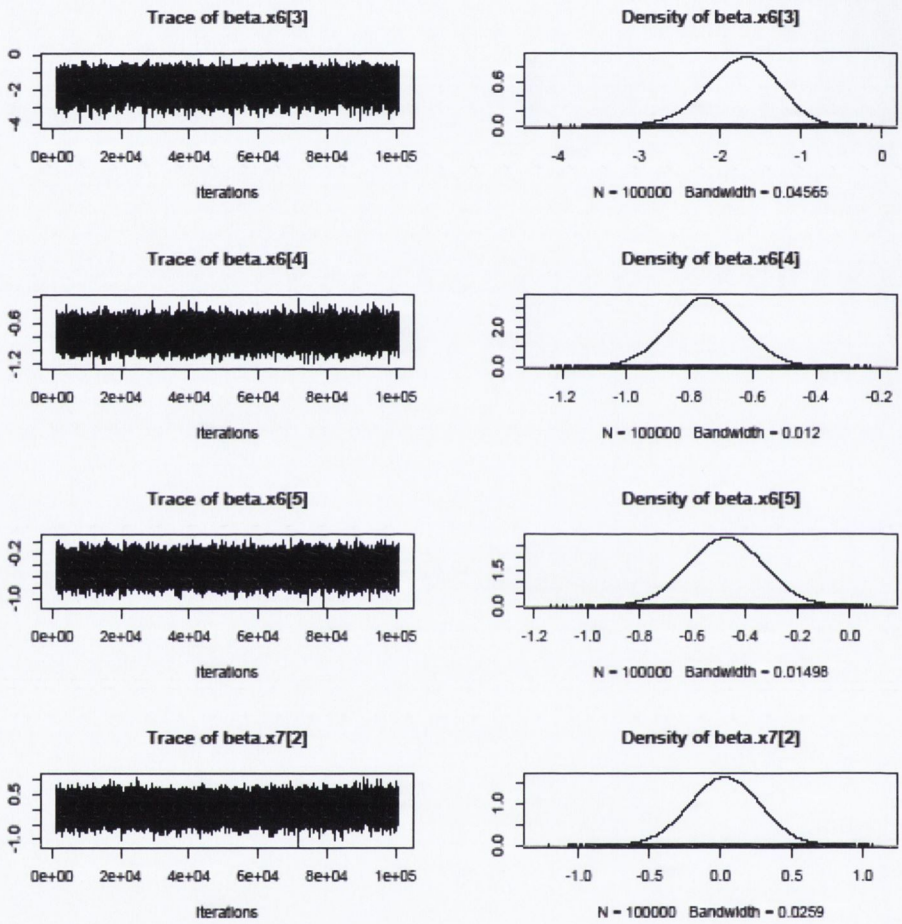
Trace and Density Plots: Single Vehicle Driver Only



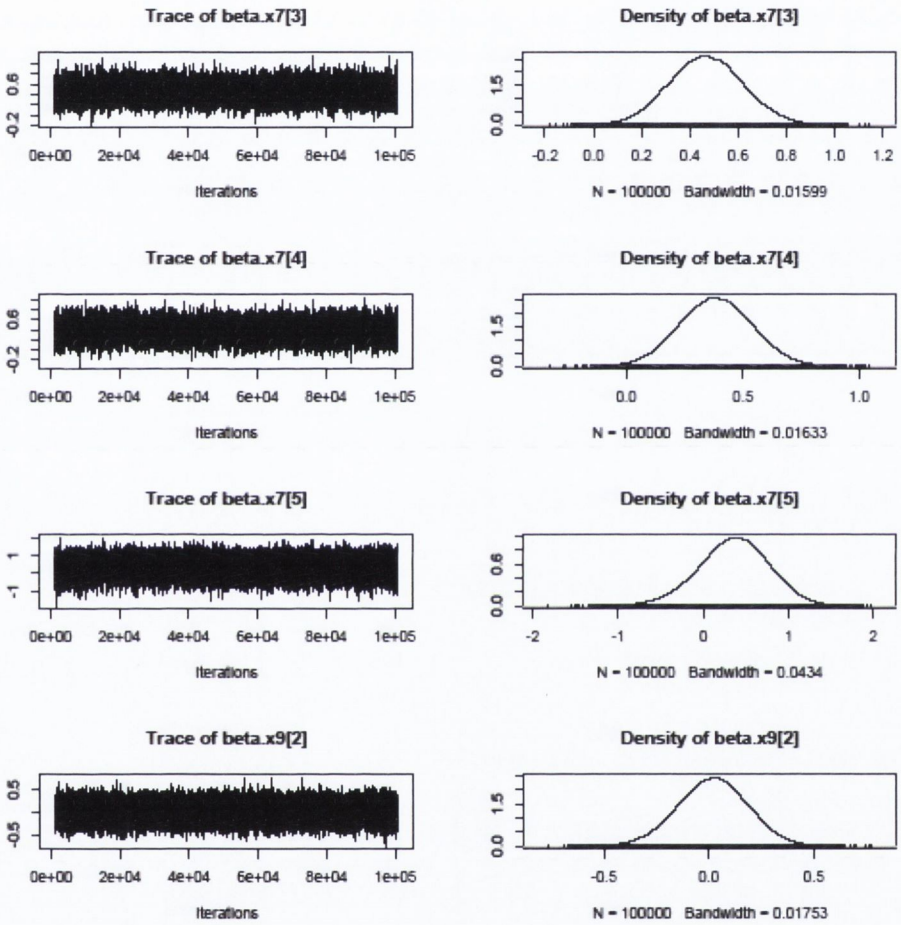
Trace and Density Plots: Single Vehicle Driver Only



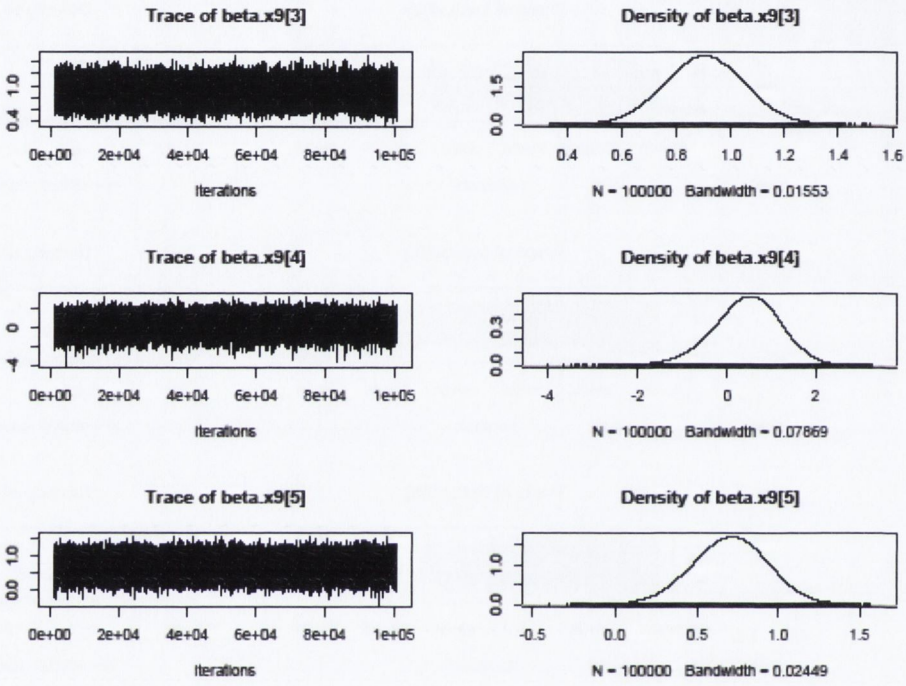
Trace and Density Plots: Single Vehicle Driver Only



Trace and Density Plots: Single Vehicle Driver Only



Trace and Density Plots: Single Vehicle Driver Only



Geweke's convergence diagnostic (Z-score)

Examination of the Geweke's convergence diagnostic output indicates that all Z-values are within -2 and +2, thus implying no differences in the means for the first and last sets of iterations.

R-Output: Single vehicle collisions (Driver only)

Iterations used = 1001:101000

Thinning interval = 1

Sample size per chain = 100000

chain1

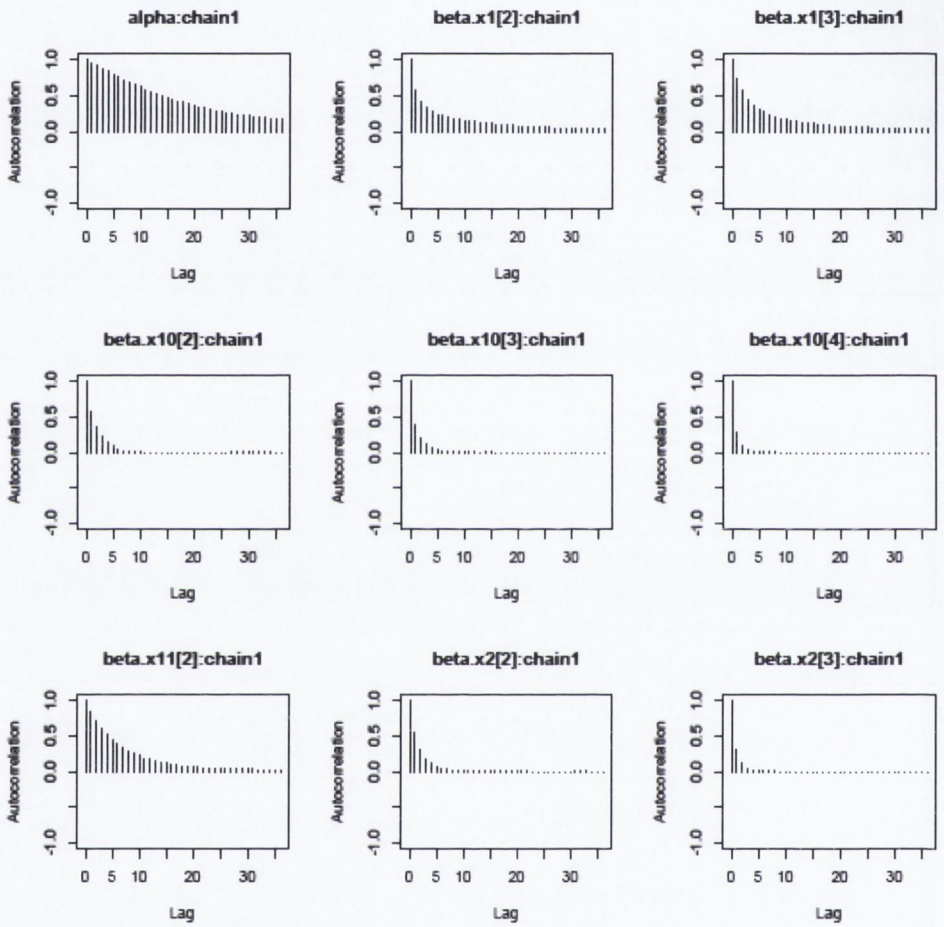
Fraction in 1st window = 0.1

Fraction in 2nd window = 0.5

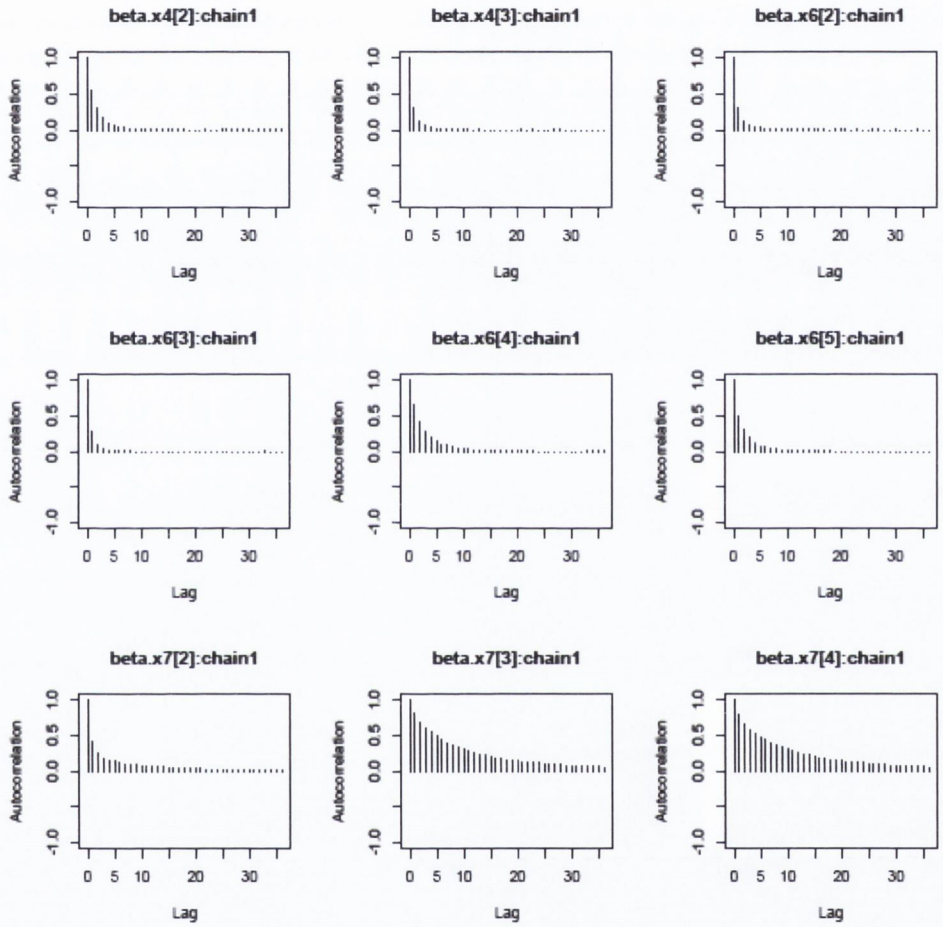
Table 52: Geweke Convergence Diagnostic (Z-score)

alpha	0.476689	**beta.x9[3]**	0.002360
beta.x1[2]	-0.453726	**beta.x9[4]**	-1.975184
beta.x1[3]	-0.551027	**beta.x9[5]**	0.115765
beta.x4[2]	-1.118097	**beta.x10[2]**	1.82247
beta.x4[3]	-0.971723	**beta.x10[3]**	1.19952
beta.x6[2]	-0.847055	**beta.x10[4]**	-1.946516
beta.x6[3]	-1.352086	**beta.x11[2]**	-0.310247
beta.x6[4]	-1.274276	**beta.x7[2]**	0.036819
beta.x6[5]	-1.370348	**beta.x7[3]**	0.151850
beta.x9[2]	-0.210950	**beta.x7[4]**	0.105251
beta.x2[2]	0.001658	**beta.x7[5]**	-0.577793
beta.x2[3]	-1.340618		

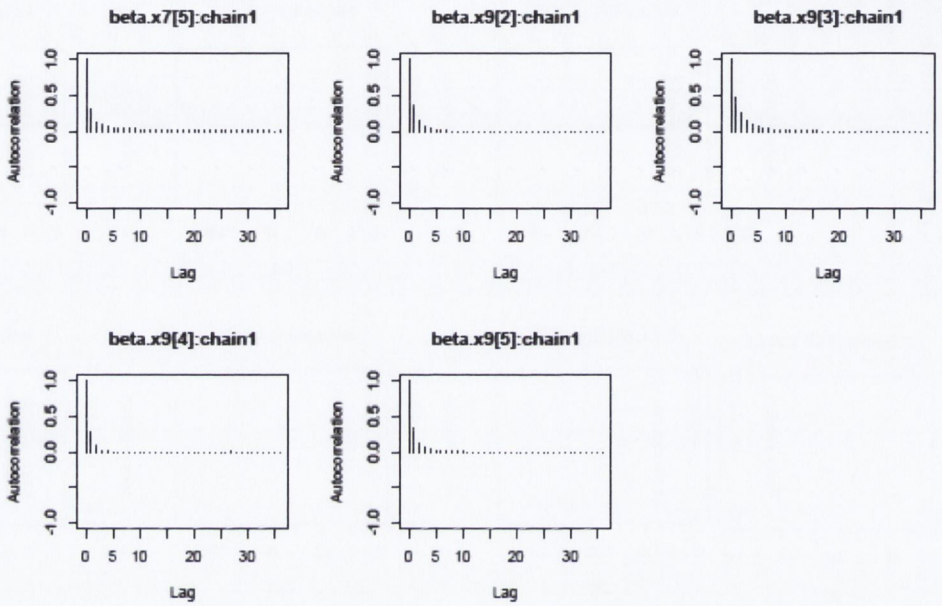
Autocorrelation plots: Single Vehicle Driver Only



Autocorrelation plots: Single Vehicle Driver Only



Autocorrelation plots: Single Vehicle Driver Only

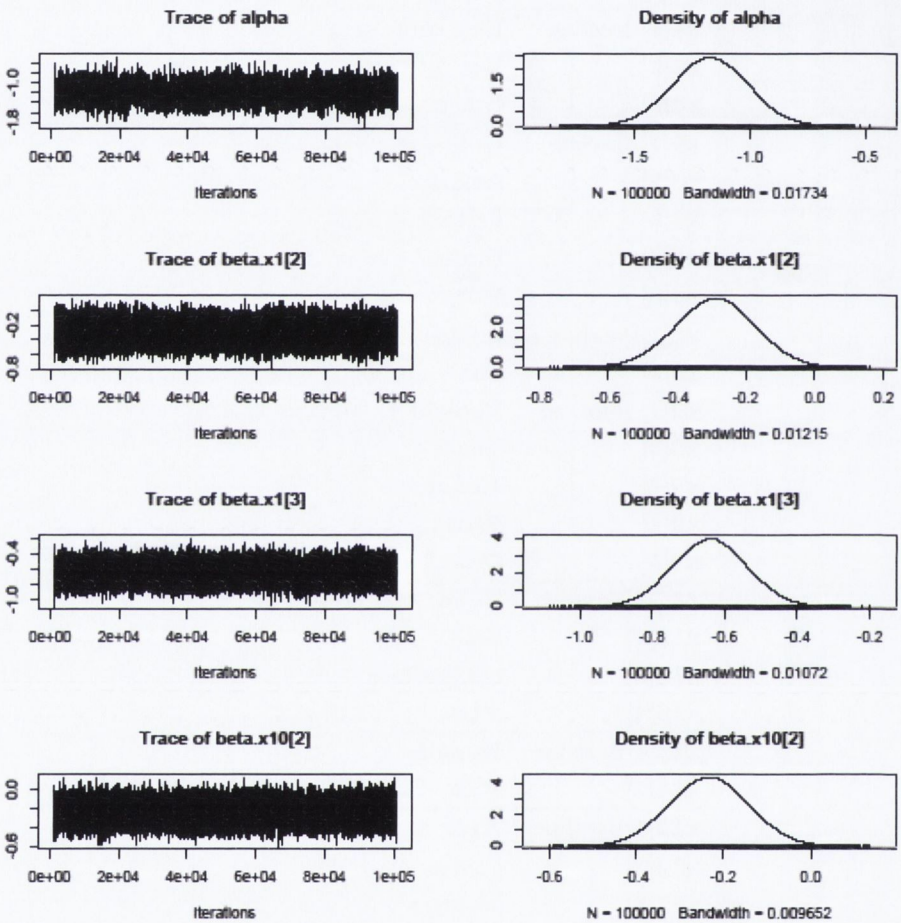


.11.2 Single Vehicle - Driver +

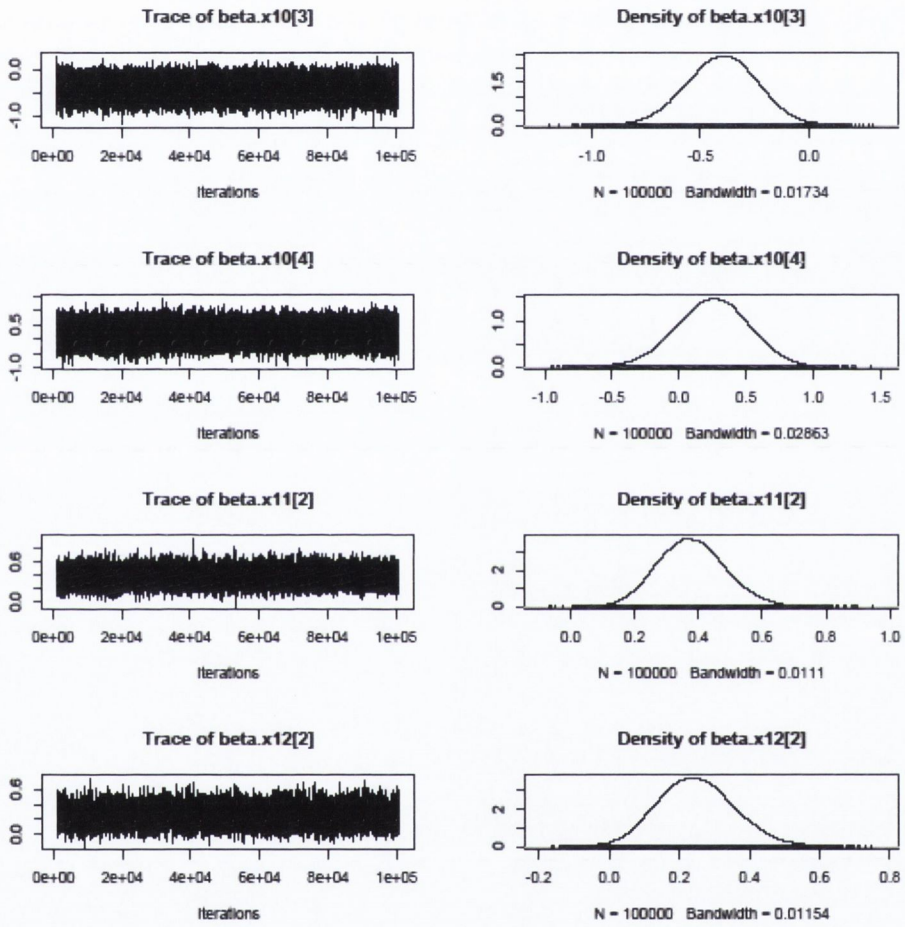
Table 53: Model Variables: Single Vehicle Driver+

Variable	
x1[1]Baseline	**Daylight**
x1[2]	Dark with street lighting
x1[3]	Dark
x4[1]Baseline	**Dry road surface**
x4[2]	Wet road surface
x4[3]	Other road surface
x6[1]Baseline	**Collision with: object** e.g. wall/pole
x6[2]	Animal
x6[3]	Parked vehicle
x6[4]	Ditch
x6[5]	Other
x8[1]Baseline	**Junction: No**
x8[2]	Yes
x9[1] Baseline	**Vehicle Type: car**
x9[2]	Goods
x9[3]	Motorcycle
x9[4]	Public service vehicle e.g. bus
x9[5]	Other
x10[1]Baseline	**Road: straight**
x10[2]	bend
x10[3]	hill/gradient
x10[4]	other
x11[1]Baseline	**Female**
x11[2]	Male
x12[1]Baseline	**Age: 40-64yrs**
x12[2]	¡ 25yrs
x12[3]	25-39yrs
x12[4]	65+yrs

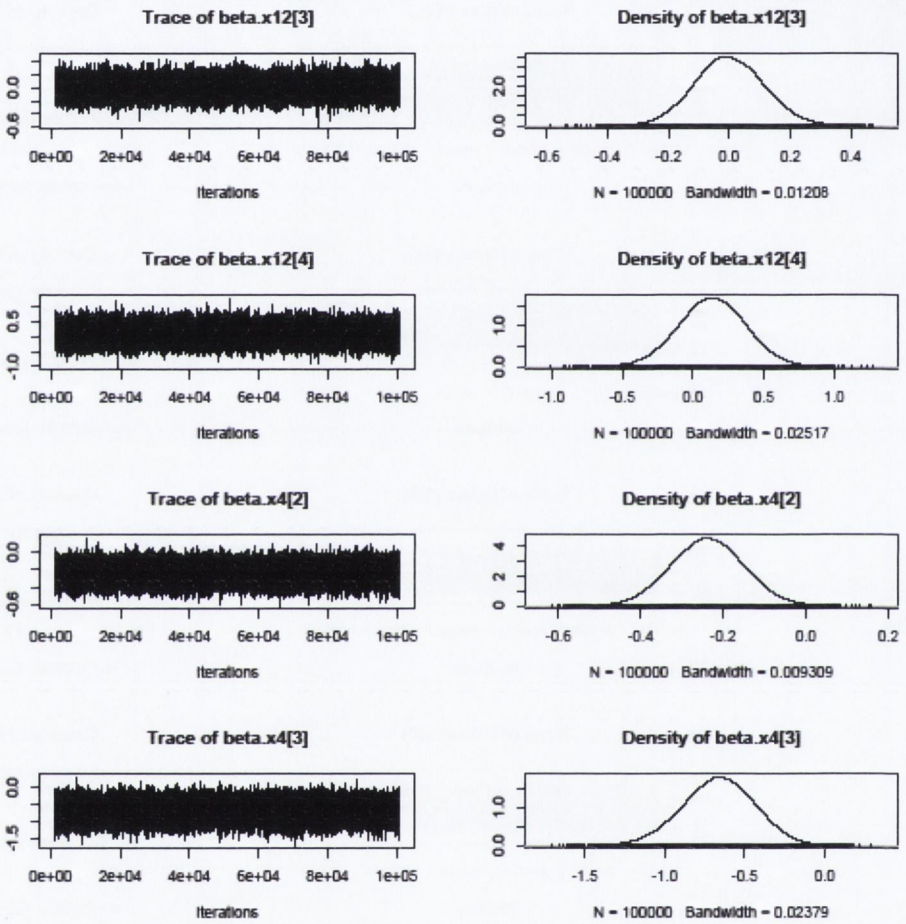
Trace and Density Plots: Single Vehicle Driver+



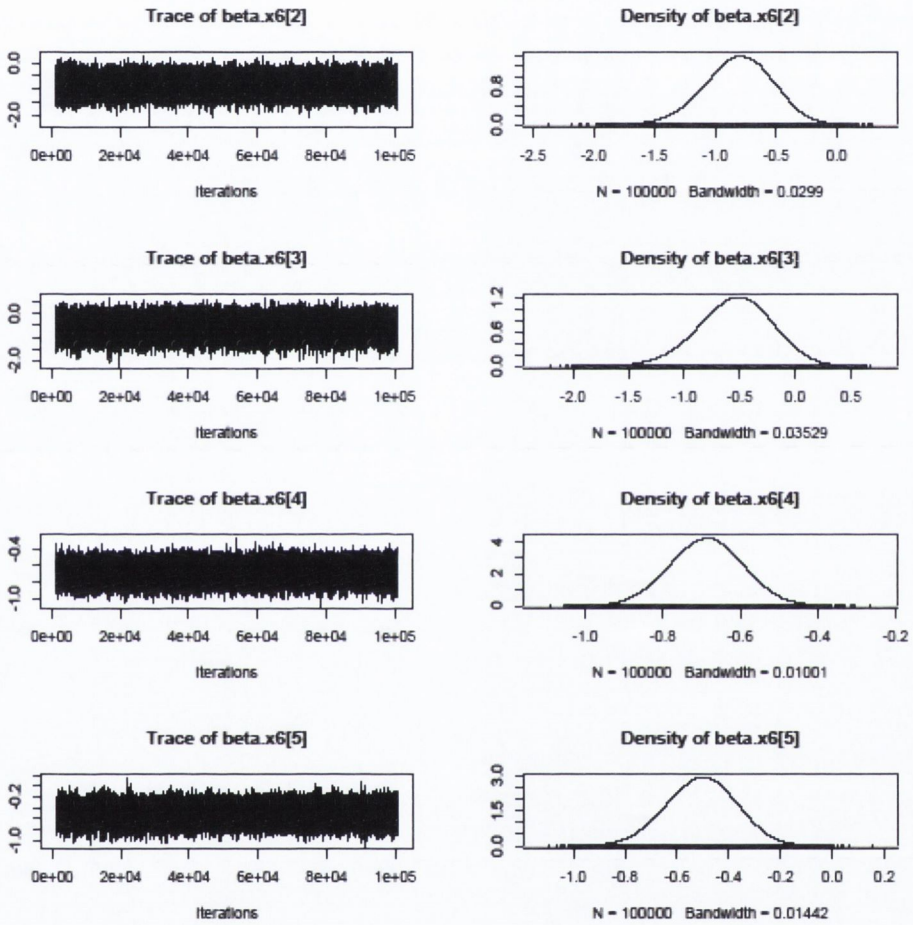
Trace and Density Plots: Single Vehicle Driver+



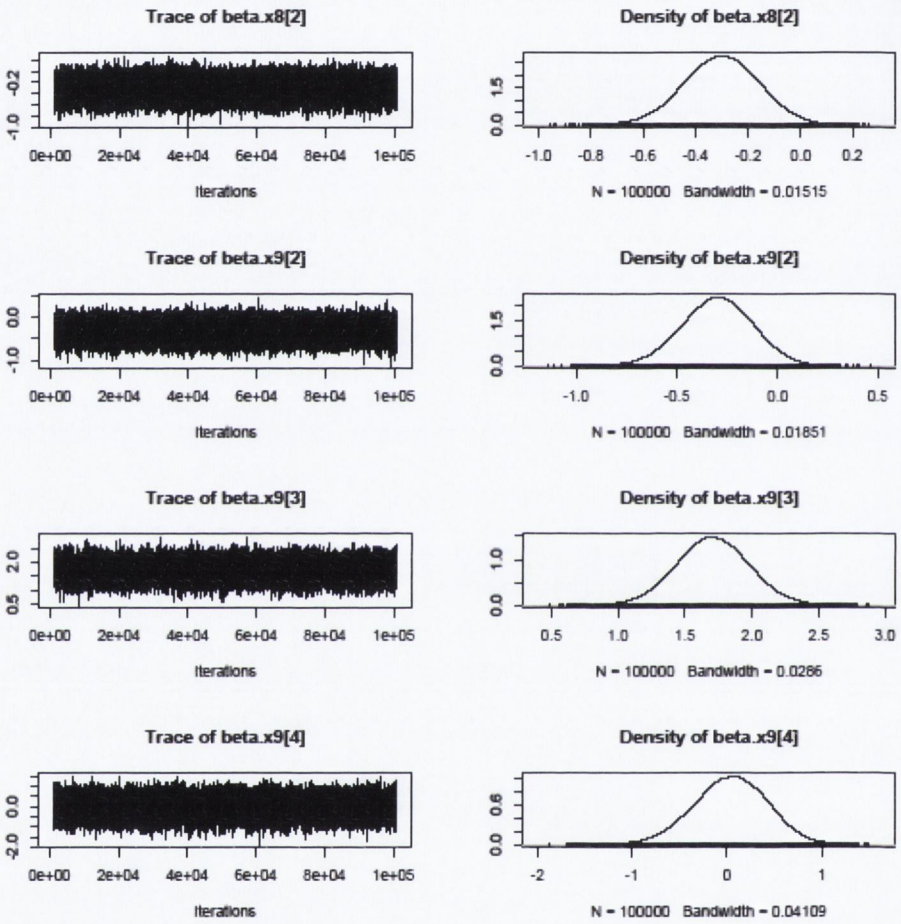
Trace and Density Plots: Single Vehicle Driver+



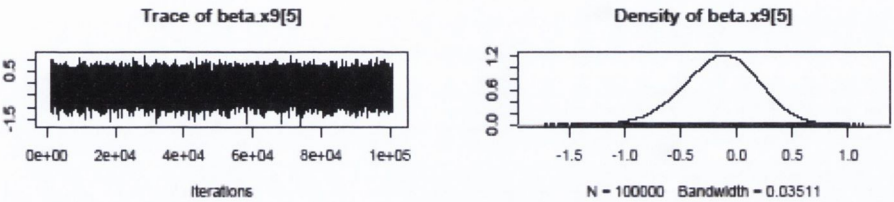
Trace and Density Plots: Single Vehicle Driver+



Trace and Density Plots: Single Vehicle Driver+



Trace and Density Plots: Single Vehicle Driver+



Geweke's convergence diagnostic (Z-score)

R-Output: Single vehicle collisions (Driver +)

Iterations used = 1001:101000

Thinning interval = 1

Sample size per chain = 100000

chain1

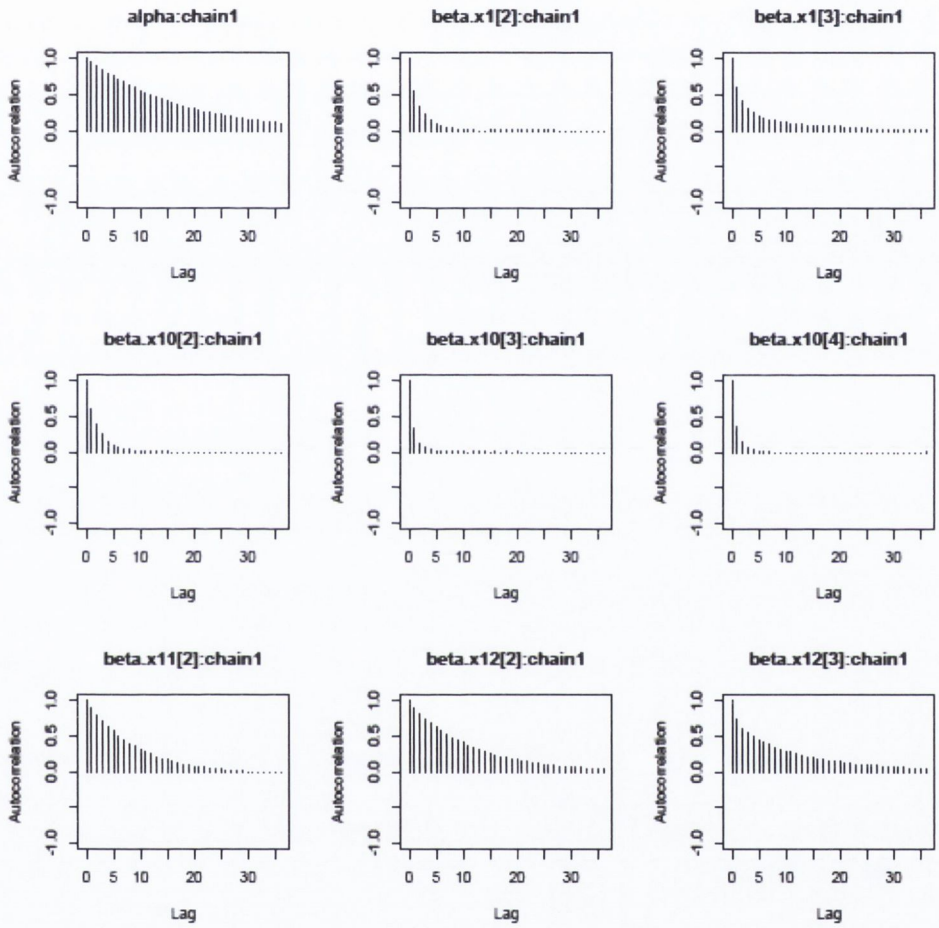
Fraction in 1st window = 0.1

Fraction in 2nd window = 0.5

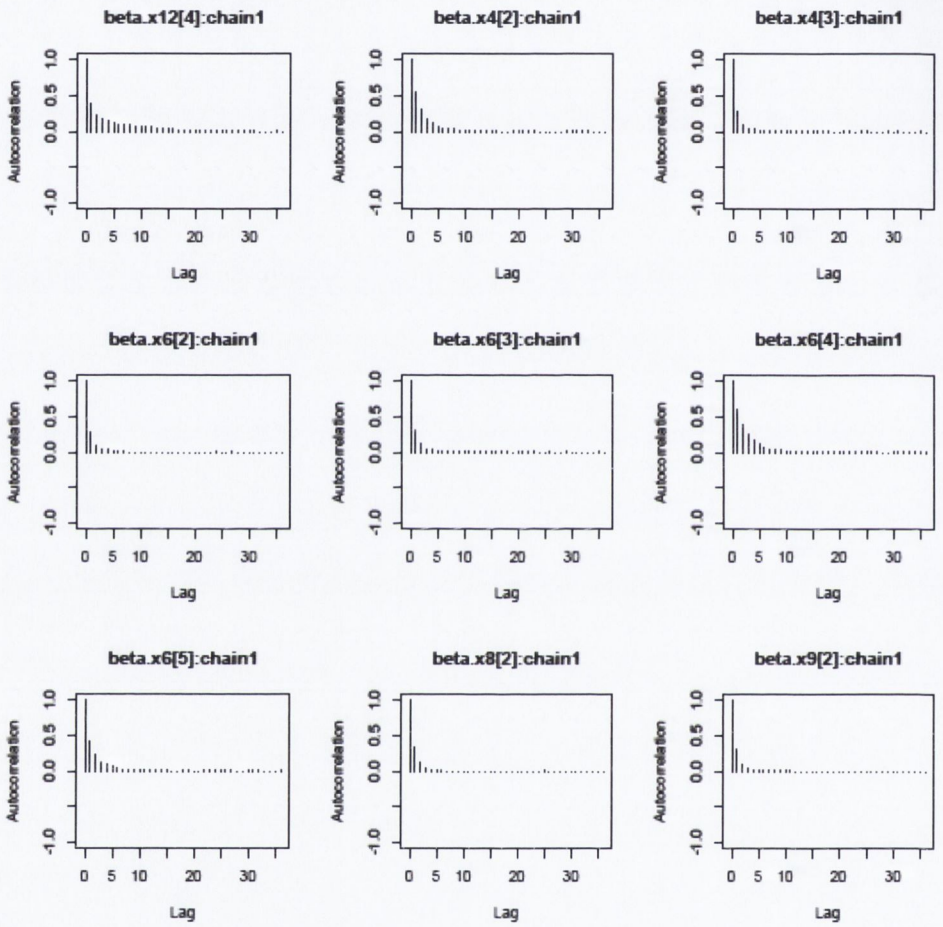
Table 54: Geweke Convergence Diagnostic (Z-score)

alpha	-0.88968	**beta.x9[3]**	-1.55104
beta.x1[2]	1.24458	**beta.x9[4]**	0.68110
beta.x1[3]	1.63552	**beta.x9[5]**	0.59260
beta.x4[2]	0.16609	**beta.x10[2]**	1.82247
beta.x4[3]	1.72862	**beta.x10[3]**	1.19952
beta.x6[2]	-0.28813	**beta.x10[4]**	0.64370
beta.x6[3]	1.32009	**beta.x11[2]**	-1.15154
beta.x6[4]	-0.16994	**beta.x12[2]**	1.25307
beta.x6[5]	0.01904	**beta.x12[3]**	1.72973
beta.x8[2]	0.14329	**beta.x12[4]**	1.64581
beta.x9[2]	0.02386		

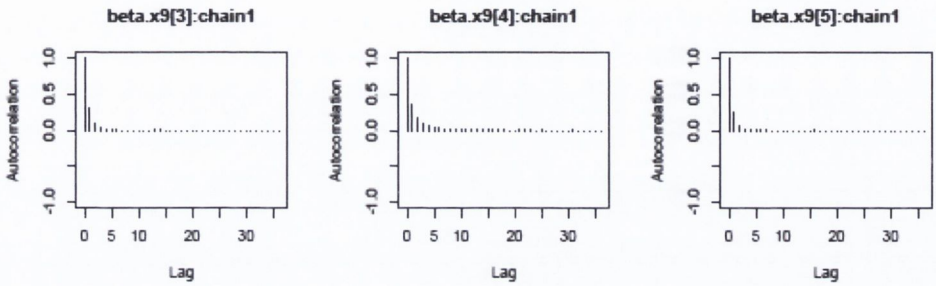
Autocorrelation plots: Single Vehicle Driver+



Autocorrelation plots: Single Vehicle Driver+



Autocorrelation plots: Single Vehicle Driver+

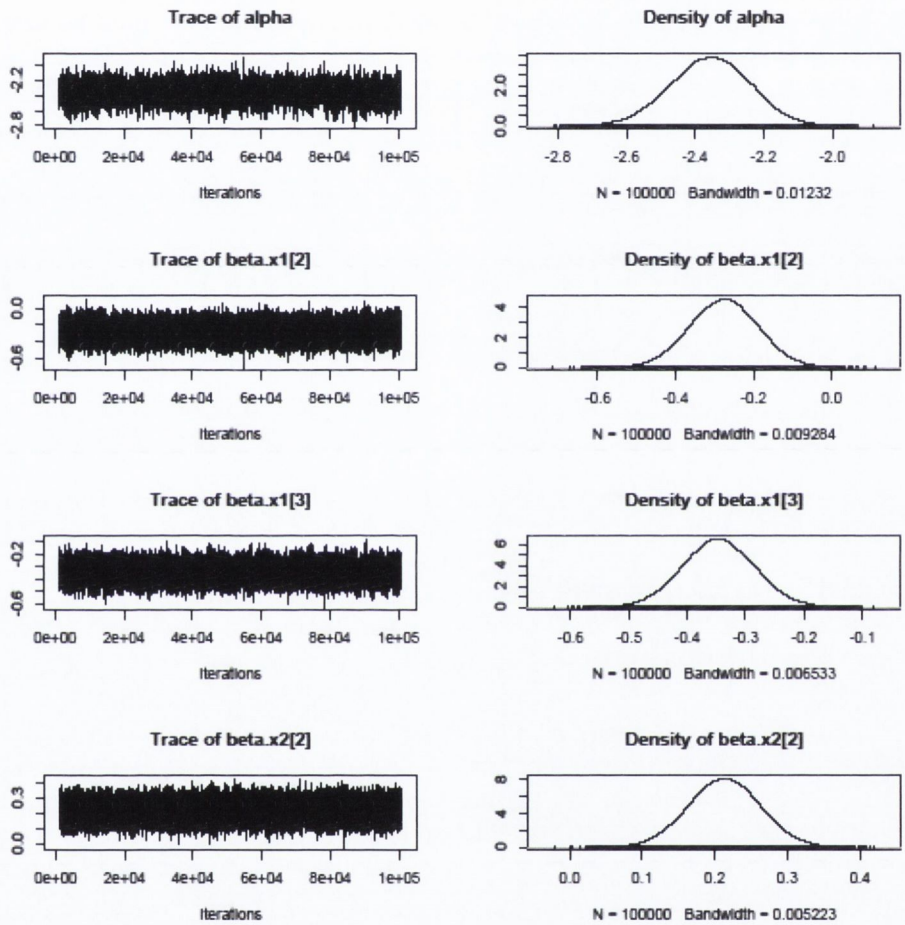


.11.3 Multi-Vehicle collisions

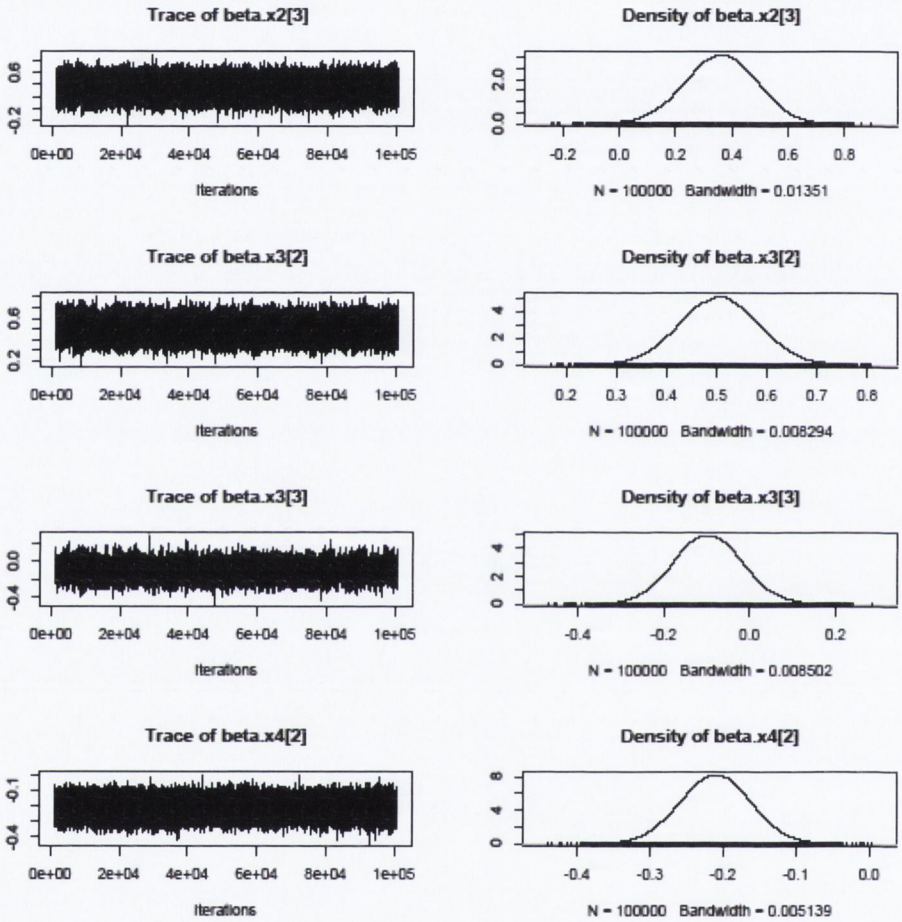
Table 55: Model Variables: Multi-vehicle collisions

Variable	
x1[1]Baseline	**Daylight**
x1[2]	Dark with street lighting
x1[3]	Dark
x2[1]Baseline	**Week day**
x2[2]	Weekend
x2[3]	Public/Bank holiday weekend
x3[1]Baseline	**National secondary road**
x3[2]	National primary road
x3[3]	Regional/local road
x4[1]Baseline	**Dry road surface**
x4[2]	Wet road surface
x4[3]	Other road surface
x6[1]Baseline	**Collision: Head-on**
x6[2]	Angle
x6[3]	Rear-end
x7[1]Baseline	**Speed limit: 50km/h**
x7[2]	60km/h
x7[3]	80km/h
x7[4]	100km/h
x7[5]	120km/h
x8[1]Baseline	**Junction: No**
x8[2]	Yes

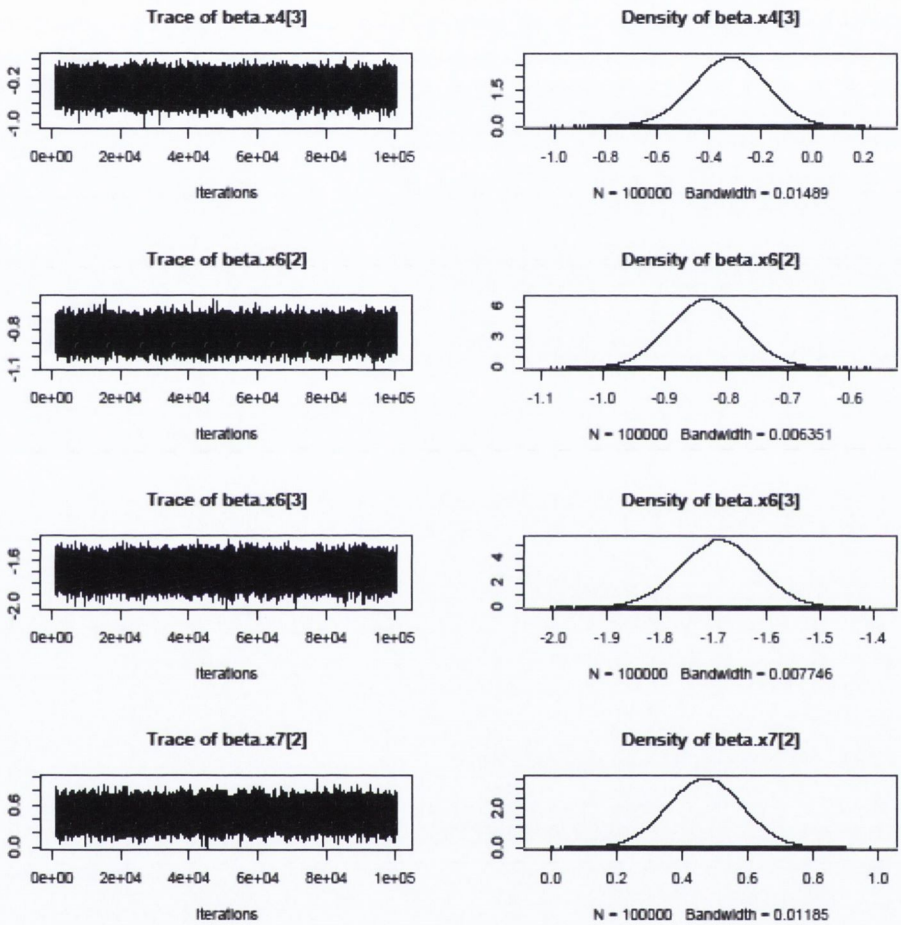
Trace and Density Plots: Multi-vehicle



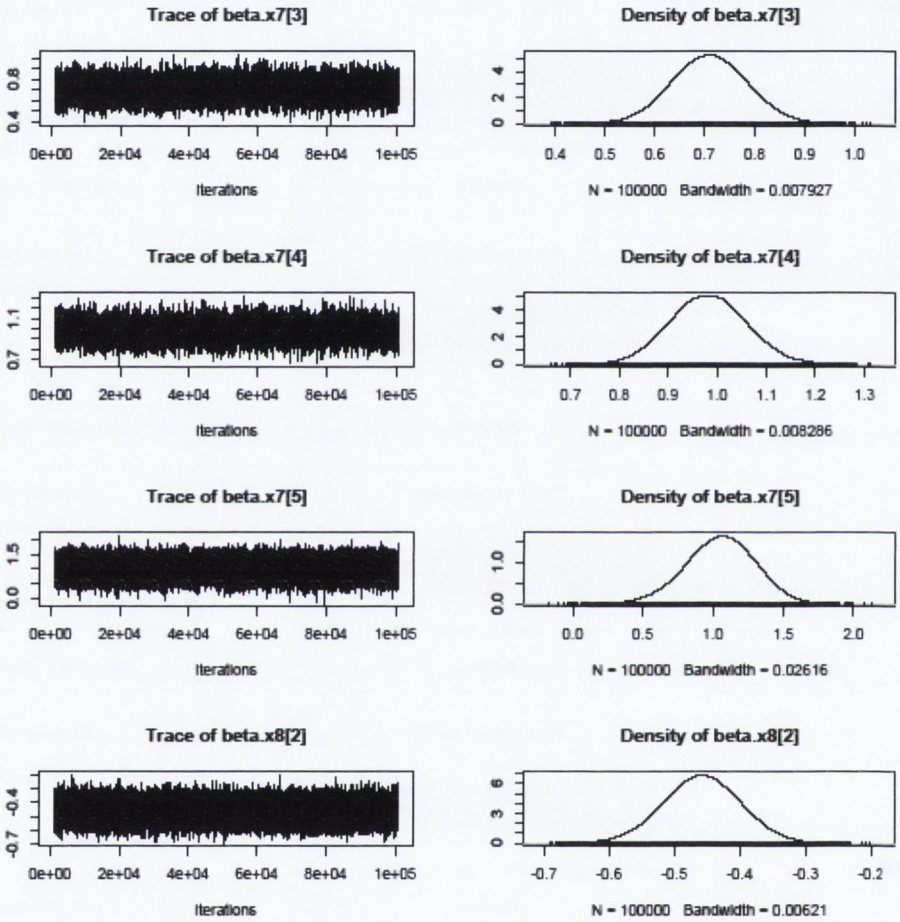
Trace and Density Plots: Multi-vehicle



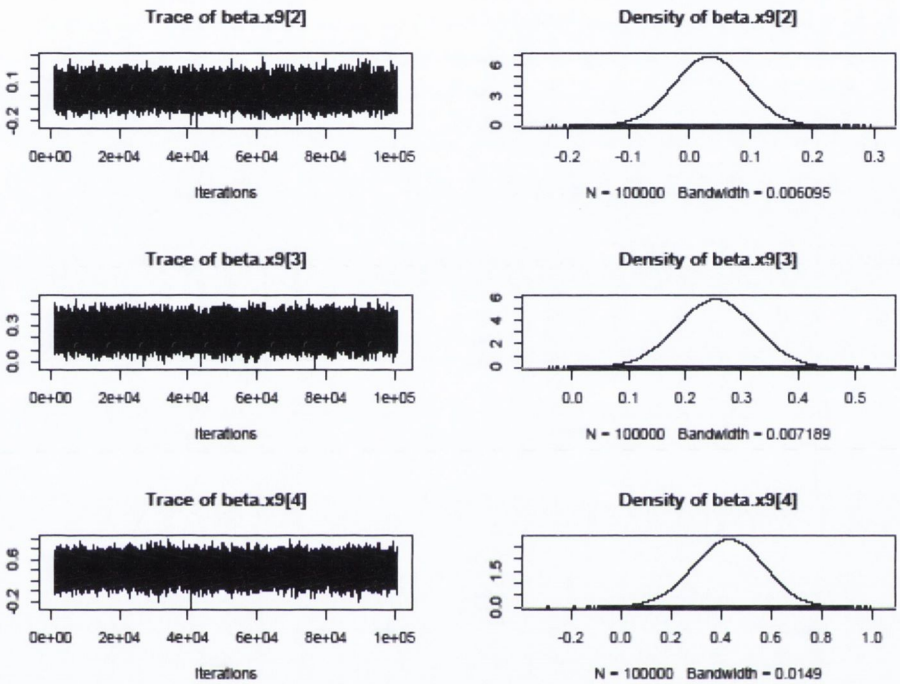
Trace and Density Plots: Multi-vehicle



Trace and Density Plots: Multi-vehicle



Trace and Density Plots: Multi-vehicle



Geweke's convergence diagnostic (Z-score)

R-Output: Multi-vehicle collisions

Iterations used = 1001:101000

Thinning interval = 1

Sample size per chain = 100000

chain1

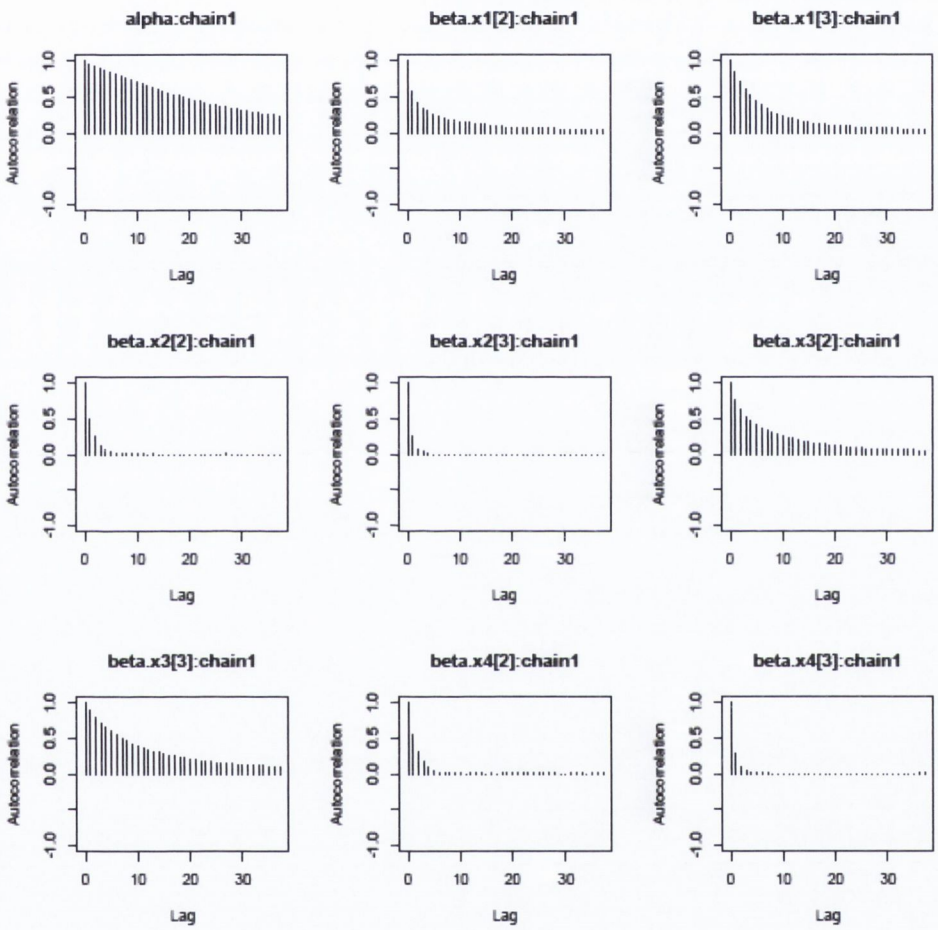
Fraction in 1st window = 0.1

Fraction in 2nd window = 0.5

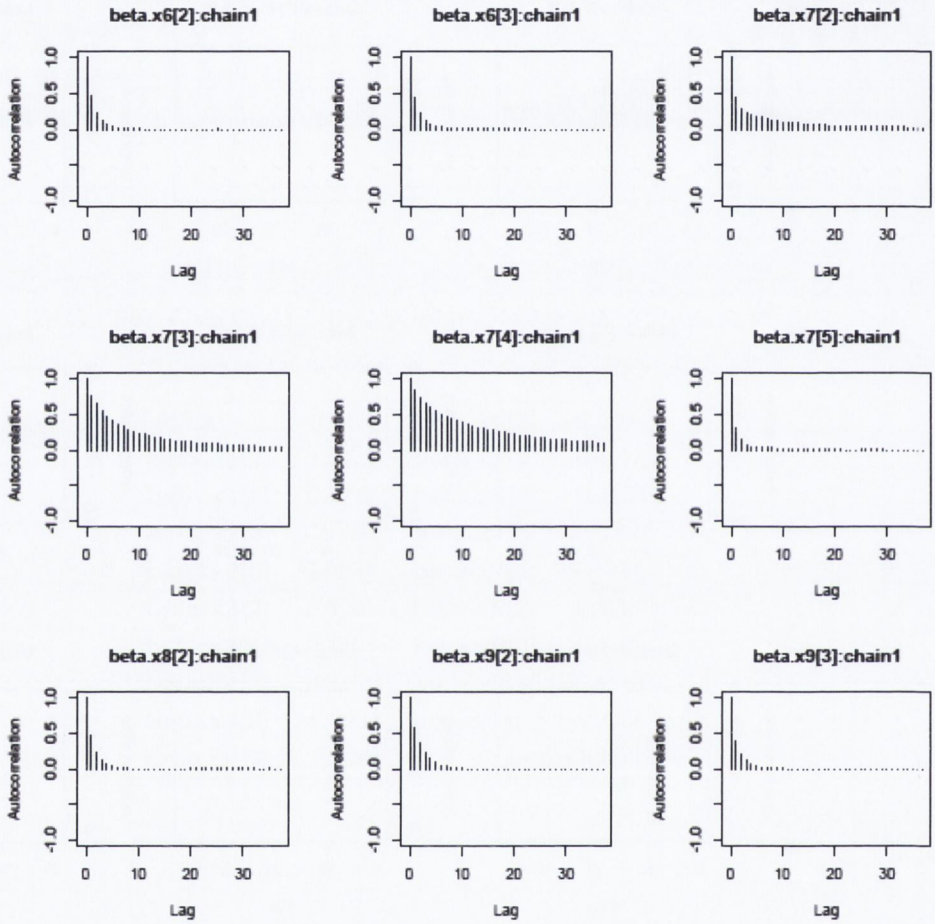
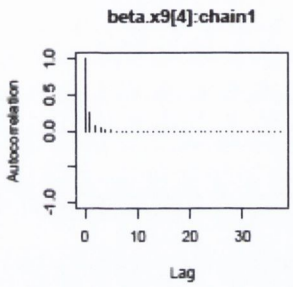
Table 56: Geweke Convergence Diagnostic (Z-score)

alpha	-0.4436	**beta.x6[3]**	0.6609
beta.x1[2]	0.5472	**beta.x7[2]**	0.4974
beta.x1[3]	0.3244	**beta.x7[3]**	0.9153
beta.x2[2]	-1.5532	**beta.x7[4]**	0.5780
beta.x2[3]	1.0834	**beta.x7[5]**	0.7410
beta.x3[2]	0.3903	**beta.x8[2]**	0.4980
beta.x3[3]	0.4365	**beta.x9[2]**	-0.1122
beta.x4[2]	0.2153	**beta.x9[3]**	-0.8394
beta.x4[3]	-0.6031	**beta.9[4]**	0.7965
beta.x6[2]	-1.5295		

Autocorrelation plots: Multi-vehicle



Autocorrelation plots: Multi-vehicle



Autocorrelation plots: Multi-vehicle