Analysing Truck Position Data to Study Roundabout Accident Risk

By

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ABSTRACT

In order to reduce accident risk, highway authorities prioritise maintenance budgets partly based upon previous accident history. However, as accident rates have continued to fall in most contexts, this approach has become problematic as accident 'black spots' have been treated and the number of accidents at any individual site has fallen. Another way of identifying sites of higher accident risk might be to identify near-miss accidents (where an accident nearly happened, but was avoided), which are likely to be much more prolific than actual accidents, therefore they are useful in identifying high-risk sites. The principal aim of this research is to analyse potentially unsafe truck driving conditions that involving harsh braking incidents (HBIs) that may indicate accident risk.

Most modern truck fleets now record position as part of fleet management. This research used position data collected by a truck fleet management company for 8000 trucks in the United Kingdom (UK) over a 2-year period (2011-2012) to identify incidents of harsh braking. This data was compared with STATS19 accident data events (specifically truck accidents) occurring in 70 selected roundabouts (284 approaches) over an 11-year period (2002-2012), to test the hypothesis that the HBIs could represent accident near-misses and therefore increased accident risk. The data used for model prediction comprised all vehicle accidents, truck accidents, HBIs, geometric properties, and traffic characteristics for whole roundabouts, within the circulatory lanes, and at approaches to the selected roundabouts. Random-parameters negative binomial (NB) count data models were used to estimate model parameters and the models were compared with fixed-parameters NB count data models.

It was found that random-parameters count data models provide better goodness of fit and more variables were found to be significant, giving a better prediction of events. It is concluded that HBIs are influenced by traffic and geometric variables in a similar way to total and truck accidents, therefore they may be useful in considering accident risk at roundabouts. They are a source of higher volumes of data than accidents, which is important in considering changes or trends in accident risk over a much shorter time. The most important variables were Average Annual Daily Traffic (AADT) and percentage of truck traffic, which were found to have a positive influence on accidents and HBIs. Regarding the geometric variables, signalisation, circulatory roadway width, number of arms and two-lane indicator were the most important factors influencing accidents and HBIs. In addition to these models, numbers of HBIs was used as an independent variable in the models of total and truck accidents, along with traffic and geometric variables. From the results it can be concluded that at all approaches, HBIs are related to total accidents along with traffic and geometric variables, which can be used to study safety measures. A good predictive model for truck accidents at M-class approaches based on HBI, traffic and geometric parameters was identified that can be used for prioritising safety at these approaches in order to make roundabouts safer. For A- and B-class approaches a better fit model were identified when HBI were used as input variable along with traffic and geometric variables compared to the model without using HBI as input variable, but the influence of HBIs was negative (high HBIs with low numbers of accidents) which is probably an indicator of future accident risk in these locations. For at-grade roundabouts, a better fit model was obtained for total and truck accidents when it is compared to the model without HBIs, but the influence of HBIs was negative; this is probably an indicator of high accident risks in these at-grade roundabouts, however further investigation is required with more observations. These results for truck HBIs could help highway authorities to identify sites of increased accident risk more rapidly and without waiting for an accident history to develop.

KEY WORDS

Road accidents, near-miss accidents, position data, truck accidents, harsh braking, roundabouts, random- and fixed-parameters count data model, traffic and geometric variables.

This thesis is dedicated to My Love, My Husband "Omar", and to my little moon "Luna"

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DECLARATION

The research described in this thesis was conducted at the Nottingham Transportation Engineering Centre, University of Nottingham between October 2011 and September 2016. I declare that the work is my own and has not been submitted for a degree of another university.

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List of Abbreviation

UK	United Kingdom
AADT	Average Annual Daily Traffic
AASHTO	American Association of State Highway and Transportation Officials
ABS	Antilock Braking System
ACC	Adaptive Cruise Control
ADT	Average Daily Traffic
AIC	Akaike Information Criteria
CAN	Controller Area Network
CC	Cruise Control
DAS	Data Acquisition System
DDWS FOT	Drowsy Driver Warning System Field Operational Test
DFT	Department For Transport
DMRB	Design Manual for Roads and Bridges
ESC	Electronic Stability Control
EU	Europe
euroFOT	European Field Operational Test
FCW	Forward Collision Warning
FOT	Field Operational Tests
GPS	Global Positioning System
HBI	Harsh Braking Incident
HGV	Heavy Goods Vehicle
ICD	Inscribed Circle Diameter
IVMS	In-Vehicle Monitoring System
LGV	Light Goods Vehicle
Ln	Natural logarithm
NB	Negative binomial
NDS	Naturalistic driving study
NTD	Naturalistic Truck Driving Study
OLS	Ordinary Least Square
R^2	Regression Coefficient
SD	Standard Deviation
SL	Speed Limiter
SRS	Speed Regulation System
US	United States

Chapter 1 Introduction

1.1 Background

The "Global Status Report on Road Safety" reports that 1.25 million fatalities are recorded annually across the whole world's road networks. The World Health Organisation has set the target of a 50% reduction in highway accident fatalities and injuries by 2020 for sustainable development (World Health Organization, 2015). In the UK, overall road accident rates have been falling for many years (Department for Transport (DFT), 2014). In an effort to continue this reduction, highway authorities maintain budgets for road safety improvements, and these must be prioritised to those locations where safety measures, such as junction improvements and resurfacing, will be most effective. In the past, priority could be given to sites with poor accident records, or 'black spots'. As accident rates have fallen, these locations have become less apparent and further methods are required to prioritise expenditure on road safety.

Real-word studies regarding the safety of the road network and its relationship to driver behaviours are a widely considered research area. This research illustrates the natural behaviour of the driver while they are driving. Generally speaking, there are three different types of on-road studies including: i) controlled on road study (small data size identifying driver behaviours due to fatigue, alcohol, or driver distraction, etc. in a short time period); ii) field observation tests (FOT) (large scale, long term driving) and: iii) Naturalistic driving study (NDS), (which focuses on treatments regarding safety) (Carsten et al., 2013).

Nowadays the vehicles using the road networks have become more sophisticated, including in the number of sensors recording data for engine management and maintenance purposes. It may be feasible that, in some cases, these data could also be used by highway authorities to provide information about the road networks. Amongst these data, truck fleet management companies often collect records of the position of vehicles within their fleet; this can be used for logistical reasons and can also be processed and combined with other data (e.g. engine speed or gear selection) to provide information about driver behaviour, for instance for use in driver training to improve fuel economy (see for instance Microlise, 2016). During the years 2011 and 2012, trucks were installed with Global Positioning System (GPS) controller Area Network (CAN) supervised by Microlise Ltd. Position data can be processed to record acceleration and Harsh Braking Incidents (HBIs). A large number of HBIs (195,297) over the UK roads and intersections were recorded over a period of 2-years for 8000 trucks. These HBIs can be seen to cluster at some roundabouts. Figure 1-1 shows a grade-separated roundabout, the red buttons indicate the 138 accidents recorded over an 11-year period (2002-

2012), and the blue buttons indicate the 728 HBIs over a 2-year period (2011-2012). This indicates that the number of HBIs is much higher than accidents. Where the incidents are due to unsafe driving, they may represent accident near-misses. It may be possible to use HBIs to identify locations with high accident risks.

Figure 1-1 Grade-Separated Roundabout (J28 on the M1) with Accident and HBI Positions

Geometric design of roundabouts is a sensitive case, as any sudden change in geometric design leads the roundabouts to be less safe as stated by Kennedy (2007). Truck rollover accidents are common at roundabouts (Kemp et al., 1987). Trucks overturn at roundabouts because of extreme speed or hard braking, while they are on adverse super elevation, as stated by Kennedy (2007). In addition, Arndt (1991) (cited in Kennedy, 2007) states that roundabouts with high inscribed circle diameter (ICD), with high speed, and when there is a high cross-fall at the circulatory lanes, leads trucks to be unbalanced. Weber et al. (2009) in a study for accommodating small and large trucks at roundabouts stated that issues with trucks at roundabouts mainly include accommodating trucks within the available geometry. This indicates that geometric design of the roundabout can highly influence truck drivers and may lead them to record HBIs and in such cases roundabouts become less safe for trucks if there were any sudden changes in its geometry. Moreover previous studies (illustrated in Chapter Two, Section 2.3) identified the influence of traffic and geometric variables on total accidents at roundabouts, and they found significant results regarding these influence. Therefore in this study, geometric and traffic variables (AADT, and percentage of truck traffic) were selected to identify their influence on total and truck accidents and on truck HBIs. This will leads examine if truck HBIs at roundabouts are influenced by similar variables that affected total and truck accidents.

The "European Large-Scale Field Operational Tests on In-Vehicle Systems" euroFOT study by Faber et al. (2011) concluded that it is not possible to predict the influence of in vehicle systems on accidents because no fully established relationship exists between driving events (e.g harsh braking) and accidents. In addition, a 100-car NDS (Dingus et al., 2006) was able to identify a large number of near-miss accidents, but they stated that they were not successful in finding a limit that prevents accidents from occurring because the sensor data was too noisy. In this study, the definition of accident near miss includes HBIs, accelerating, and steering and these events are considered as vehicle kinematics. Practically, kinematics that is related to accident near-misses related to a number common driving conditions, which are not considered as indicators of accidents (for instance just because a traffic light turned red). For the current study (thesis) the available HBI data acquired from Microlise Ltd. indicates a sudden deceleration, indicating bad forward planning for the situation ahead (e.g. roundabout, junctions, traffic lights changing). As discussed earlier HBIs were clustered at some roundabouts, therefore there may be incidents that occurred because of signalisation (i.e. traffic light turned yellow or red) and these incidents cannot necessarily be considered as an indicator of un-safe driving. But Figure 1-1 shows that HBIs did not occur only when entering the roundabouts but also at greater distances from the entry. This shows they may occur for other reasons concerning traffic or geometric design of the roundabouts or may be because of driver behaviour. In addition, the roundabouts included in this study were signalised, un-signalised, or partially signalised (for more detail about roundabout characteristics see Section 3.3.1). Therefore, a novel approach of this study is to explore if there is a relationship between total and truck accidents with HBIs along with traffic and geometric variables.

1.2 Aims and Objectives

The aim of this research is to explore the use of HBI records to identify roundabout accident risks.

The objectives are to:

- Characterise the total and truck accidents at a number of roundabouts.
- Characterise the incidence of harsh braking at a number of roundabouts.
- Compare these characteristics to factors known to influence accident rates.
- Investigate the relationship between accidents and HBIs.
- Explore if an analysis of HBIs can add (contribute) to accident data for road safety studies.
- Make recommendations for taking this idea forward.

The findings from this research may be useful for the identification of locations with high accident risks through an analysis of HBIs.

1.3 Thesis Outline

The thesis is structured into eleven chapters. The background, aims and objectives and thesis structure are presented in this chapter.

Chapter Two presents the literature review. This includes a review on accident safety and factors at road segments, and a review of statistical modelling and methodology applied to accident data. In addition, a review is made of accident near-misses and HBIs and how driver behaviour influences them is illustrated in detail. Finally, this chapter provides a review of safety at roundabouts and the various factors influencing roundabout safety in the UK and other developed countries.

Chapter Three illustrates the data sources, and describes the procedures and methods that have been carried out for investigating truck sensor data (as regards HBIs), total accidents, and truck accidents. Regression analysis and the statistical modelling procedure are provided in this chapter.

Chapter Four presents general total and truck accident analysis, which includes general total and truck accident trends, restricted contributory factors, and a characterisation of accidents at roundabout approaches by their distance from the give way line. This chapter also includes regression analysis, showing the linear relationship between total and truck accidents and AADT and the percentage of truck traffic based on the number of lanes, number of arms, type of grade, and traffic control type of a roundabout.

Chapter Five presents the statistical modelling as applied to total accidents and truck accidents using random and fixed-parameters NB count data models. A comparison is also made between the models developed for total accidents in this research and models from previous research.

Chapter Six describes incidents of harsh braking in general, characterising the HBIs according to distance, the percentage of HBIs during peak and off-peak periods. This chapter concludes with regression analysis, showing the linear relationship between HBIs and AADT and the percentage of truck traffic based on the number of lanes, number of arms, type of grade, and traffic control type.

Chapter Seven presents the statistical modelling applied to HBIs using random and fixed-parameters NB count data models.

Chapter Eight provides a comparison between the models investigated for truck HBIs and for total and truck accidents.

Chapter Nine presents design considerations and road markings, shape of Central Island, truck apron, and a comparison of geometric parameters studied in this thesis from the Design Manual for Roads and Bridges (DMRB TD16/07, 2007; and DMRB TA78/97, 1997).

Chapter Ten presents the models identified for total and truck accidents when they are related to HBIs along with traffic and geometric parameters for different roundabout categories, and for different approach categories.

Chapter Eleven gives summary and conclusions, followed by recommendations for future research, references and list of conferences, publication, and submitted papers.

Chapter 2 Literature Review

2.1 Safety Performance of Vehicles at Road Segments

2.1.1 Overview

Road transportation is considered as a basic infrastructure facility. Road transport authorities are responsible for promoting the safety of road networks, and as such their principal aim is to make the road safer, and to reduce fatalities and injuries arising from accidents at road networks. The main cause of many accidents is drivers including all vehicle drivers, and trucks in particular are a type of vehicle whose effect on the safety of the road network should be taken into account, as they cause many fatalities and serious injuries, because of their size, the freight they carry, and the different and difficult manoeuvres that they require compared to cars and other types of vehicles (Carstensen et al., 2001).

The main problem statement as discussed in Chapter One is that the accident trend has been falling for many years, so the principal aim of this section is to explore how the accident trend has changed over a time period in the UK and other developed countries. In addition, the main contributory factors to accidents, as collected by the police, are examined. This will be followed by a section discussing prediction models applied to accident data in the area of transportation and the illustration of random-parameter modelling of data, which is a recent development in traffic safety studies and is used in this thesis to analyse accidents and HBIs at roundabouts. It is also important to identify the main factors causing accidents in the road network, which is discussed in a later section, and this section is ended with a summary and conclusions. All of these sections may benefit the interpretation of accident analysis, and models are developed in this thesis relating to total accidents and truck accidents in particular.

2.1.2 Accident Background Research

Before addressing roundabouts, it is important to identify the trend in total and truck accidents at road sections over the years in the UK, United States (US), and the Europe (EU), to explore how these trends have changed, and what are the targets that the transportation safety policy put forward, in addition to explore how they achieved these goals. Generally speaking, the DFT (2013) defines accidents as “personal injury occurring on the public highway (including footways) in which at least one road vehicle or a vehicle in collision with a pedestrian is involved and which becomes known to the police within 30 days of its occurrence” (p.9). However, this means that people, property and the environment will all be involved in that accident when it occurs. Casualties, fatalities, serious and slight accidents will arise from that accident and the DFT (2013, p.9) defines these terms as follows:

“Casualty: A person killed or injured in an accident. Casualties are sub-divided into killed, seriously injured and slightly injured”.

“Fatal accident: An accident in which at least one person is killed; other casualties (if any) may have serious or slight injuries”.

“Serious accident: One in which at least one person is seriously injured but no person (other than a confirmed suicide) is killed”.

“Slight accident: One in which at least one person is slightly injured but no person is killed or seriously injured”.

In order to achieve the goal of reducing casualties, the UK government, for the first time, set a target (reduction target) during the year 1987; the target was to decrease the number of fatalities and serious injuries by 30% by the year 2000. Their aim was successful, and by 2000 the number of casualties (fatalities and serious injuries) was reduced by 39% and 45%, respectively. However, the government continued setting targets and it was found that by 2009 slight casualties and serious casualties, including fatalities, decreased by 37% and 44%, respectively, over the 10-year period (1999–2009) (Witty et al., 1999).

Figure 2-1 shows the traffic and reported casualties by severity. On average, the yearly decline in the number of fatalities was 10%, except for the increase in 2011. Fatalities and serious casualties have decreased over the last decade. Comparing 2013 to 2005–2009 average, the average of serious casualties declined by 20% (DFT, 2014). The Department for Transport addressed a number of factors that affect this decline, including training and education of road safety, vehicles and highway engineering and technologies developed, in addition to speed reduction. Moreover, the government is more educated on how to provide better accessibility that takes care of people—for example, the construction of a major trauma centre in England designed to care for patients involved in accidents; in addition to these factors, economic factors have resulted in the decrease of fatalities (DFT, 2014).

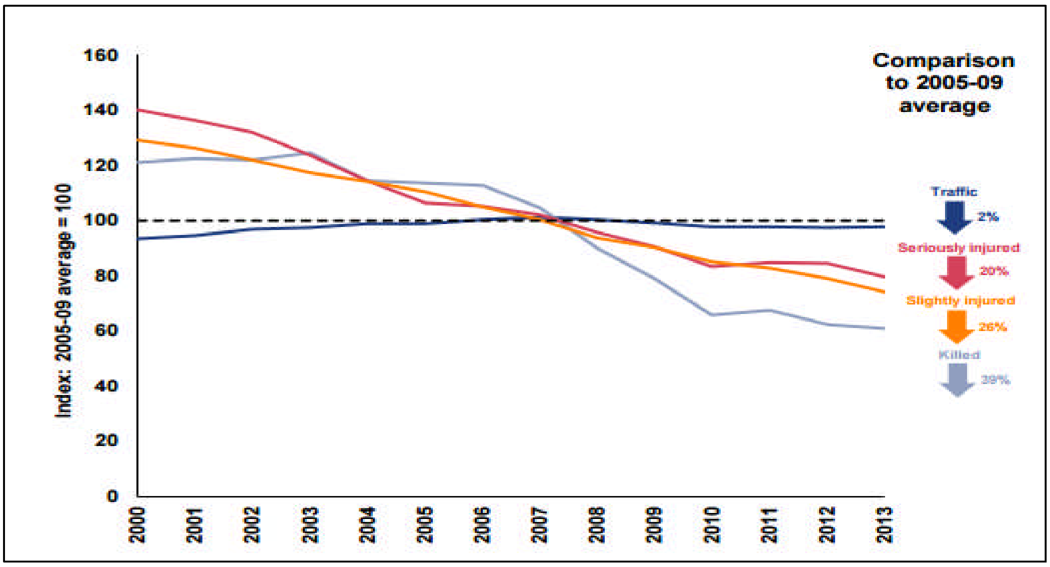

Figure 2-1 Reported Casualties by Severity and Reported Traffic, Great Britain (GB): 2000 to 2013 (DFT, 2014)

In the UK, fatalities, and serious injuries including all vehicles in accidents were 392,022 in 2003, which had declined to 252,913 by 2013. In 2003 and 2013 respectively, serious injuries and fatalities including goods vehicle (heavy goods vehicles (HGVs) and light goods vehicles (LGVs)) numbered 30,659 (7.8%) and 19,210 (7.6%), respectively. The percentages of fatalities, serious and slight casualties for accidents involving goods vehicles were 2.2%, 13.3% and 84.5%, respectively. While for other types of vehicles the percentage of fatalities, serious and slight injuries was 1.1%, 13.1%, and 85.8%, respectively. In addition, on motorways, accident fatality rates per vehicle miles travelled involving goods vehicles was 2.3, including goods vehicle occupants and pedestrians killed from being hit by goods vehicles; the corresponding rate for cars (i.e. rate of fatalities of car occupants and pedestrians being hit by cars) was 1.3 per vehicle miles travelled. On A roads, accident fatality rates per vehicle miles travelled involving goods vehicles was 6.1 relative to a rate of 5.7 fatalities including car accidents (DFT, 2014). This indicates that the percentage and rate of fatalities from goods vehicles is higher compared to other vehicles, which shows that truck accidents are particularly dangerous for road users (drivers, pedestrians) and for other vehicle types.

In the EU, road traffic fatalities decreased by 60% during a 20-year period (1991 to 2010). Overall, from 2005 to 2008, about 1,728,000 people were recorded as fatalities and serious injuries in all types of traffic yearly, of which 113,000 were fatalities and serious injuries in accidents involving trucks (Trucks V, 2013). They found that the majority of fatalities and serious injuries (55 to 65%) in truck accidents are passenger car occupants. The declining trend in the EU is due to important developments in infrastructure and the safety of vehicles, and also driver behaviour has improved because of rules on using seat belts, driving within the speed limit, and drivers are driving less while they are drinking alcohol due to the rule changes that the government set for drivers.

In conjunction with reducing accidents, over the past ten years, the fatality rate decreased by 25% in United States. In 2013, 32,719 people were killed in motor vehicle accidents and 3,964 were killed in accidents involving large trucks. Of the fatalities, 71% involving large truck accidents were other vehicles occupants, 17% were large truck occupants, and 11% were pedestrians (non-occupants); 47% of both large trucks and other vehicle fatal accidents were because of proceeding straight manoeuvre when the accident occurred. 66% of large truck fatal accidents occurred during the daytime, and 79% occurred on weekdays (US Department of Transportation, 2014).

Regarding danger and accidents related to HGVs, Carstensen et al. (2001), who represent the Danish Transport Group, analysed 21 accidents involving trucks. Their aim was to identify whether the presence of trucks increased accident risk because of their weight/size or driver behaviour. In this study, 23 truck drivers and 21 drivers of passenger cars were included in 21 accidents. They found that, during the 21 accidents, one truck driver and 10 passenger car drivers or pedestrians were killed, and three truck drivers and 15 passenger car drivers were injured. Further, 15 truck drivers and 11 passenger car drivers were involved in accidents because of their behaviour. The authors concluded that, compared to other vehicle accidents, truck accidents were more serious because of their configuration, size, and manoeuvrability, and reduced braking, all of which contributed to collisions. Additionally, casualties increased when speeds were high, and the size and weight of trucks resulted in more casualties and serious injuries relative to other types of vehicles. When accidents occur because of HGVs, the other vehicles involved in the accidents will suffer more damage than trucks. In addition, Grygier et al. (2007) stated that when accidents occurred between trucks and other types of vehicles, the majority of fatalities were drivers and passengers of other types of vehicles.

It can be concluded that the number of accidents, deaths, and seriously injured casualties has decreased over the last decades, which supports the thesis problem statement that the number of accidents decreased; therefore, other methods are required to identify and report unsafe conditions and acts. In addition, it is clear that truck accidents are dangerous for the road network as higher numbers of non-truck drivers are included in accidents involving trucks, as illustrated by the above studies. Therefore, it is important to consider analysis of trucks regarding the safety of road network.

2.1.3 Reported Contributory Factors

In order to understand why and how accidents occur, since 2005, the police force in the UK, in addition to recording vehicle and casualty details, reports contributory factors that are included in the STATS19 form as an important section. STATS19 information includes road accidents involving injury on the public highway. This system collects around 50 types of data regarding time, date, accident severity, vehicle details, contributory factors, etc. The aim of STATS19 is to determine various accident situations, enabling road safety policies to be developed in order to reduce accident and casualty numbers. Codes for the STATS19 fields can be found in Appendix A. However, the reported contributory factors depend on the views of the police officer, although they recorded these factors to prevent accidents in the future. However, the percentage occurrence of some factors is lower than others because the required evidence is not available after the accidents occurred. STATS19 includes a list of 77 contributory factors (see Appendix A); they constitute nine groups: “Road environment, Vehicle defects, Injudicious action, Driver/rider error or reaction, Impairment or distraction, Behaviour or inexperience, Vision affected by external factors, Pedestrian only factors (casualty or uninjured) and Special codes”. For instance, in the category of “Driver/rider error or reaction”, code 405 refers to “failed to look properly” (DFT, 2012).

From 2009 to 2013, the majority of contributory factors recorded for all vehicles and HGVs related to driver/rider behaviour varied from 40% to 45%. From 2011 to 2013, “Failed to look properly” is the most frequently reported factor recorded for HGVs (25–27%) and for all vehicles (24%), followed by, “Failure to judge another person’s path or speed”, which ranks second for HGVs (14–15%) and for all vehicles (12–13%). According to DFT only 3% of accidents involving HGV occurred because of sudden braking (DFT, 2014). However, it is probably safe to assume that many other accidents caused by the other contributory factors, led to emergency (harsh) braking. This implies that HBIs may indicate accident risks, even if they are not all associated with accidents.

2.1.4 Accident Prediction Models

Fridstrom et al. (1995) state it is impossible to predict accidents (where, when, and by whom an accident occurred), because in nature accidents are random. They stated that the way to find an answer to these questions is to predict approximate accident numbers. During a time period a high number of accidents are accumulated over a sufficient area, which leads to a level of predictability that can be explained by statistical and mathematical relationships. In addition, they believe that these predictions can be applied to road accidents.

A number of studies have been undertaken on predicting accidents using linear regression models, namely ordinary least squares (OLS) regression, especially in the early stages of analysis. Researchers, for instance Mohamedshah et al. (1993), and Daniel and Chien (2004), have used linear regression to identify the effect of traffic and geometric characteristics on truck accidents at roadway segments, however, using linear regression models to represent accidents is inappropriate, as accidents usually are not distributed normally, and linear models have normality restrictions. Moreover, Salifu (2004) states that OLS regression is unsuitable for analysing accident rates, as there are some statistical characteristics within these regressions, for instance the "homoscedascity[1]" hypothesis. In addition, accident rates are estimated to be negative values. However, it is a fact that accident data are counts that are "sporadic, discrete, and non-negative", and their distributions are more similar to a Poisson distribution. Thus, Poisson regression distribution is introduced to count data.

For instance, Joshua and Garber (1990) identified the effect of roadway geometric and traffic characteristics on truck accidents using multiple linear and Poisson regression[2] models at a given section of a roadway segment in Virginia. They found that Poisson regression better described the relationship between truck accidents and roadway geometrics and traffic characteristics than linear regression. Another study on modelling truck accidents with respect to geometric and traffic variables was undertaken by Maiou and Lum (1993). Similar to previous studies, they used Poisson and Linear regression models. They found that linear regression models could not describe adequately the distribution of random, discrete, and non-negative vehicle accident events. According to their findings, the Poisson regression could have the majority of the statistical properties required in model development.

However, the basic approach of the Poisson regression posits that variance and mean are equal, and that this brings inaccurate accident predictions. In most cases, variance is either greater than the mean (over-dispersed data) or lower than the mean (under-dispersed data). In this case, Negative Binomial (NB) approaches are appropriate for predicting accidents at road

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[1] "Equal variance of the error terms for all values of the predictor variable" (Salifu, 2004, p. 69).

[2] Truck Accident = 0.015237 $(SCR)^{0.0577}$ $(ADT)^{0.5024}$ $(TPERCNT)^{0.5731}$
Where:
SCR is the slope change rate
ADT average daily traffic
TPERCNT is the truck percentage

segments and intersections, which remove the restrictions of variance equal to the mean; this regression distribution is suitable for data that are "count, discrete and nonnegative". In the case of over-dispersion, NB is used to predict count data, and in the case of under-dispersion, the gamma distribution is used to predict accidents (Washington et al., 2011).

Mannering and Bhat (2014) provide a summary of previous studies on accident prediction models, and according to this summary a number of studies have analysed accidents using Poisson regression count data models, and a number of studies have been undertaken on NB and gamma models. These studies explain in detail the main factors influencing accidents, but they estimated that all parameters are fixed across the observations. Lord and Mannering (2010) illustrate that if the models were estimated with fixed parameters across the observations, the result will be biased, and probably, incorrect conclusions will be drawn with respect to the independent variables. For this reason, random-parameters count data models were introduced by researchers. Random-parameters models were found to be an addition to the random-effects models. However, only the constant will be random across the observations in the random effects model, while random-parameters models let some or all independent variables vary across the observations. The random-parameter model explains unobserved heterogeneity from one observation to another (Lord and Mannering, 2010).

A number of factors, including vehicle design, driver behaviour, traffic, roadway and environment features, and the change in the response of driver to external factors, in addition to the difficulty in the relation between the vehicles, affect accidents when they occur. Therefore, because of the inherent complexity of accident causation, it is a complex process to gather all pertinent information at the time when accidents occur, which leads to problems with predicting accidents because of the unavailability of some data. These factors are known as unobserved heterogeneity (the variation in the performance of the dependent variable that is not explained by the variation in the independent variable). For instance, the influence of lane widths on accidents and their severity changes from one roadway segment or from one intersection to another due to weather condition or time-varying traffic, in addition to driver behaviour and responses to changes in widths; information concerning these parameters is generally unavailable for prediction purposes. Consequently, results of the effect of lane widths may vary between different observations (Mannering et al., 2016). For example, for a sample of road sections having different lane widths, the estimated results indicate that 80% of wider lanes are associated with higher numbers of accidents, while the other 20% are associated with lower, or all lane widths have higher or lower numbers of accidents but their effects vary from one road section to another, probably because width has no effect on driver behaviour (i.e., not all drivers record accidents at higher/lower width), or maybe because lower accidents are recorded in fine weather or during non-peak periods, or in contexts having different geometric features etc. For this reason the random parameters approach was considered in analysing count data.

2.1.5 Methodological Approach of Random-Parameters Model

As discussed earlier, the random parameters model allows for unobserved heterogeneity from one road section to another. There is a methodological approach to implement this, as discussed in detail by Washington et al. (2011) and Anastasopoulos and Mannering (2009). Below is a description of the random parameters methodology applied to count, non-negative, discrete data.

In a Poisson regression model, the probability of a road segment *i* (road segment or intersection including roundabouts) having a number of accidents (n_i), which is a nonnegative integer, is:

$$P(n_i) = \frac{EXP(-\lambda_i)\lambda_i^{ni}}{n_i!} \qquad (2\text{-}1)$$

Where $P(n_i)$ is the Poisson probability of road segment *i* having n_i accidents, and λ_i is the Poisson parameter of road section *i*, which is equal to *i*'s predicted accident numbers $E[n_i]$ (i.e.($\lambda_i = E[n_i]$).

When Poisson parameter λ_i (dependent variable) is specified as a function of independent variables, Poisson regression models λ_i can be estimated. In roundabouts for example, the independent variables might include traffic volume and geometric information. The most common model that relates to accident number specified by Poisson regression λ_i with independent variables is the log-linear model:

$$\lambda_i = EXP(\boldsymbol{\beta X}_i) \text{ which is equivalent to } LN(\lambda_i) = \boldsymbol{\beta X}_i \qquad (2\text{-}2)$$

where $\boldsymbol{X}_i$ is the independent variable *i*

$\boldsymbol{\beta}$ is the coefficient of the independent variable

Based on equation (2-2), the expected number of accidents or any other events is $E[n_i] = \lambda_i = EXP(\boldsymbol{\beta X}_i)$. Based on the fact that the observation $\boldsymbol{X}_i$ is known, but the value of $\boldsymbol{\beta}$ is unknown, it can be predicted when the likelihood function is maximised as:

$$L(\boldsymbol{\beta}) = \prod_i \frac{EXP[-EXP(\boldsymbol{\beta X}_i)][EXP(\boldsymbol{\beta X}_i)^{n_i}]}{n_i!} \qquad (2\text{-}3)$$

It is easier to estimate the function (2-3) by taking natural logarithm (ln) of $L(\boldsymbol{\beta})$, as follows:

$$\ln L(\boldsymbol{\beta}) = \sum_i^n[-EXP(\boldsymbol{\beta X}_i) + n_i\,\boldsymbol{\beta X}_i - \boldsymbol{ln}(n_i!)] \qquad (2\text{-}4)$$

As discussed in Section 2.1.4, the basic approach of Poisson regression is that variance and mean are equal ($E[n_i]$ = $VAR[n_i]$), however this basic approach cannot always be applied to the data. If the two variables were not equal, as discussed earlier, either the data is under-dispersed ($E[n_i]$>$VAR[n_i]$, which indicates that the mean is greater than the variance, or over-dispersed ($E[n_i]$ < $VAR[n_i]$), in which case the mean will be less than the variance; this results in a wrong standard error[3] of the independent variables, thus an erroneous conclusion could be drawn. In that case, it is essential to re-write the model using NB distribution, which does not have this restriction and leads the variance to be different from the mean by adding the term $EXP(\varepsilon_i)$ ["a gamma-distributed error term with mean 1 and variance α^2"] to Eq. (2-2). The resulting equation will be (Washington et al., 2011):

$$\lambda_i = EXP(\beta X_i + \varepsilon_i) \qquad (2\text{-}5)$$

The form of the NB distribution function is:

$$P(n_i) = \frac{\Gamma\left[\left(\frac{1}{\alpha}\right)+n_i\right]}{\Gamma\left(\frac{1}{\alpha}\right)n_i!} \left(\frac{\frac{1}{\alpha}}{\left(\frac{1}{\alpha}\right)+\lambda_i}\right)^{\frac{1}{\alpha}} \left(\frac{\lambda_i}{\left(\frac{1}{\alpha}\right)+\lambda_i}\right)^{n_i} \qquad (2\text{-}6)$$

where $\Gamma(.)$ is a gamma function

The resulting likelihood from the formulation of (2-6) is given as:

$$L(\lambda_i) = \prod_i \frac{\Gamma\left[\left(\frac{1}{\alpha}\right)+n_i\right]}{\Gamma\left(\frac{1}{\alpha}\right)n_i!} \left(\frac{\frac{1}{\alpha}}{\left(\frac{1}{\alpha}\right)+\lambda_i}\right)^{\frac{1}{\alpha}} \left(\frac{\lambda_i}{\left(\frac{1}{\alpha}\right)+\lambda_i}\right)^{n_i} \qquad (2\text{-}7)$$

In order to allow parameters to vary across the roadway segments and intersections, Greene (2007) used random parameters to produce an estimation procedure that accounts for unobserved heterogeneity (i.e. independent variables that may change across the road segment or intersections), which enhances Poisson and NB count-data models with random parameters. In order to let variables change across the observations in count data models, the independent variables are drawn as:

$$\beta_i = \beta + \varphi_i \qquad (2\text{-}8)$$

where φ_i is "a randomly distributed term for instance may be it have a normal distribution with mean 0 and variance α^2)" (Anastasopoulos & Mannering, 2009). It should be noted, that a parameter considered random in the random parameters model a variable if the Standard Deviation (SD) of the parameter distribution is statistically different from zero; if not, it

[3] Standard error is defined as "the square root of the variance of the sampling distribution of a statistic" (Washington et al., 2011, p. 452).

remains fixed across the observations. In that case the random parameters model consists of a mix of fixed and random parameters across the observations.

With Eq. (2-8), the Poisson model will be written as λ_i/φ_i = EXP (βX_i), and the NB model will be written as λ_i/φ_i = EXP (βX_i + ε_i). The log-likelihood for the estimation of random parameter model is written as:

$$LL \ = \ \sum\nolimits_{\forall_i} ln \int_{\varphi_i} g(\,\varphi_i)\; P\left(\frac{n_i}{\varphi_i}\right) d\varphi_i \tag{2-9}$$

"where g (·) is the probability density function of φ_i" (Anastasopoulos & Mannering, 2009; Washington et al. , 2011).

2.1.5.1 Halton Draws

Analytically, the estimation of maximum likelihood for the random parameter count data models is difficult to compute and is infeasible, because of the number of numerical integrations required for the Poisson or NB function with respect to the distribution of the parameters that are random; for this reason, simulated maximum likelihood estimation is used with standard Halton draws[4] to evaluate the integral illustrated in Eq. (2-9). There are a number of sequences available to evaluate the likelihood functions (Random, Halton etc.). Any of these sequences can be used and eventually a good approximation is estimated. In order to get accurate probability estimation with as few draws as possible, a number of piece of research show the best draw of φ_i from the probability density function in order to estimate probability$P\left(\frac{n_i}{\varphi_i}\right)$. Greene (2007) stated that random draws are used as a standard approach to simulate estimated models, but cautioned that when computing a large sample with large models this approach requires a high number of computations to the extent that it becomes a waste of time. Thus, for mixed logits, Bhat (2001) and Train (1999) compared standard Halton sequences to pseudo-random sequences[5] for small dimensions of (≤5), and found that numerical integration using fewer Halton draws speeds up the model computation without deterioration in the performance of the simulation. In addition, they stated that for numerical integration a small number of Halton draws is as effective as a large number of random draw. In addition, Bhat (2003) compared Standard Halton sequences to Scrambled

[4] "The standard Halton sequence is designed to span the domain of the S-dimensional unit cube uniformly and efficiently (the interval of each dimension of the unit cube is between 0 and 1)" (Bhat, 2003, p.840).

[5] Or it is called the pseudo Monte-Carlo simulation method in which it evaluates "multidimensional integrals entails computing the integrand at a sequence of "random" points and computing the average of the integrand values. The basic principle is to replace a continuous average by a discrete average over randomly chosen points" (Bhat, 2003, p.838).

Halton sequences[6] and both to pseudo-random sequences for high dimensions of (>5) and found that 100 Scrambled Halton draws have the same accuracy as 150 Standard Halton draws and 500 pseudo-random draws. Note that the dimension aspect is based on the number of estimated independent random parameters in the model. For instance, a data set with two random parameters (normally distributed) leads to a two-dimensional integration for estimating the maximum likelihood estimation.

All studies undertaken in the area of transportation examining accidents at road sections have used Halton draws to simulate the maximum likelihood (Milton et al., 2008; Anastasopoulos & Mannering, 2009; El-Basyouny & Sayed, 2009b; Wang et al., 2009; Granowski & Manner, 2011; Ukkusuri et al., 2011; Venkataraman et al., 2014). In the area of biology/agricultural (Rigby et al., 2003) housing energy (Carlsson and Martinsson, 2007) and educational statistics (Flannery et al., 2009) has used Halton draws to estimate the maximum likelihood estimation.

2.1.5.2 Marginal Effect

In Poisson and NB model estimation, one can derive the marginal effect, which illustrates the "relative magnitude between the dependent and independent variables based on parameter estimates" (Anastasopoulos & Mannering, 2009, p.154). The marginal effect is the variation in the number of dependent variables due to one-unit change in the independent variables, *x*. It is computed as partial derivative, $\partial\lambda_i/\partial x$ where λ_i is defined in Eq. (2-2) and (2-5) (for Poisson, NB with fixed parameters, respectively), or as in equation of $\lambda_i \setminus \varphi_i = EXP\ (\beta X_i)$, and $\lambda_i \setminus \varphi_i = EXP\ (\beta X_i + \varepsilon i)$ (for Poisson, NB with random-parameters models, respectively), which is based on the model that could be used to predict the dependent variable – either fixed or random Poisson NB models (Anastasopoulos & Mannering, 2009).

However, the general equation for computing the average marginal effect is computed as (Garnowski & Manner, 2011):

$$\frac{1}{n}\sum_{i=1}^{n} ME_{x_{ik}}^{\lambda_i} = \frac{\partial\lambda_i}{\partial x_{ik}} = \frac{1}{n}\sum_{i=1}^{n} \beta_k EXP(\boldsymbol{X}_i\boldsymbol{\beta}) \tag{2-10}$$

[6] Scrambled Halton sequences have been produced to improve the performance of standard Halton sequence in high dimension of >5, because in high dimensional sequences standard Halton sequences can be highly correlated (Hess et al., 2006).

where ME represents the marginal effect, x_{ik} is the k^{th} estimable independent variable for the road section i, β_k is the predicted coefficient for the k^{th} independent variable, and λ_i is the predicted number of accidents for road section i.

For instance, in case we need to observe the marginal effect of x_1 (an independent variable) with respect to y (dependent variable) in a standard Poisson model, having two statistically significant independent variables (x_1 and x_2) related to accident number y, the marginal effect is computed as follows:

If estimated y is

$$\lambda_i = e^{\beta_\circ+\beta_1 x_1+\beta_2 x_2}$$

Taking partial derivative with respect to x_1, $\frac{d\lambda_i}{dx_1}$

$$\frac{d\lambda_i}{dx_1} = \beta_1 \, e^{\beta_\circ+\beta_1 x_1+\beta_2 x_2}$$

means

$$\frac{d\lambda_i}{dx_1} = \beta_1 \lambda_i$$

where:

$\beta_\circ$ is the constant, β_1 is the estimated coefficient of the first variable, and β_2 is the estimated coefficient of the second variable.

This process is repeated for each observation then the average is reported.

LIMDEP software computes and reports marginal effect for the fixed and random parameters models at the means of x, based on the equation below (Garnowski & Manner, 2011):

$$\left.\frac{\partial E\left[\frac{y_i}{X}\right]}{\partial x_k}\right|_{\bar{\boldsymbol{X}}} = \beta_k \exp(\bar{\boldsymbol{X}}'\beta) \qquad (2\text{-}11)$$

where $\bar{\boldsymbol{X}}$ is the mean of the independent variable.

2.1.5.3 Random Parameters Model Applications

In the area of transportation, the first study on the random parameters model was undertaken by Milton et al. (2008). In this study mixed logit was used instead of NB models. Mannering and Bhat (2014), in a summary, show several studies undertaken in the area of accident prediction models on road segments, some of which are presented below. Lord and Mannering (2010) state that random parameters models are statistically better than traditional fixed parameters. However, there is a criticism of the estimation of random parameters models, because when the parameter is random each observation has its own $\boldsymbol{\beta}$ (the estimated coefficient of the independent random parameter) so it is difficult to transfer to another location. But in case when the SD of the variable is statistically different from zero this means that on individual road sections or at intersections including roundabouts, unobserved heterogeneity exists. Unobserved heterogeneity still exists in case of using fixed parameters models for estimating such data. Consequently, using and transferring a fixed parameters model that determined to have bias leads to problems as this bias is due to unobserved heterogeneity.

Some of the studies undertaken using random-parameter count data models, for instance Anastasopoulos and Mannering (2009), in a study on road segment compared the random to fixed parameters model, and found that the efficiency and overall fit of the random parameters model is better than the fixed parameters NB model. They studied the influence of a number of geometric and traffic variables, as well as road surface conditions on the number of accidents and found that "AADT, the roughness index reading, rutting indicator reading (1 if five year average rutting readings are below 0.2 in: 0 otherwise), road segment length, median barrier presence indicator (1 if present; 0 otherwise), inside shoulder width indicator (1 if ≥5 ft; 0 otherwise), and horizontal curvature" (p.156) to be randomly distributed across the road segment. In this study they used 200 Halton draws to estimate the maximum likelihood function.

Another study applying this model by El-Basyouny and Sayed (2009) observed "392 urban arterials clustered in to '58 corridors' in the city of Vancouver, BC". They found that length of the segment, AADT, density of crosswalks, land use regarding business locations, density of un-signalised intersection, and the numbers of lanes between signals have a significant influence on accident frequencies and their effect was found to vary across the investigated corridors. In addition, Garnowski and Manner (2011) stated that the random parameters NB model was an appropriate model for their data in estimating factors that influence accident rates on German Autobahn connectors. Geometric variables such as steeper curve indicator, length of deceleration lane, and position of the steepest curve on the ramp were found to vary across the observations, the influence of AADT and percentage of truck traffic was fixed across the observations.

In another study on random parameter application, Ukkusuri et al. (2011) addressed the issue of "unobserved heterogeneity for modelling pedestrian crash frequencies" for "New York City at the census tract level" using random parameters NB model for the rate of pedestrian accident. They studied variables describing the "socio-demographic" and "built-environment characteristics" of the tracts. A number of variables in this study were found to vary across the observations, which shows their heterogeneous effects on the pedestrian accident numbers across the observed locations. In addition, Venkataraman et al. (2014), in an accident study on 1,153 directional road segments in the state of Washington, US, found that in 19 models out of 21 log-likelihood was significantly improved when they used random parameters NB models relative to the fixed parameter NB model. They stated that the improved log-likelihood is due to the parameters being random across the observations.

In other research areas (i.e., not transportation and safety) Rigby et al. (2003) in the UK used a random parameter logit model of the demand for the genetically modified (GM) food. They stated that the random parameters model better fits the data when they compared to the fixed parameters model. In another research area Carlsson and Martinsson (2007) applied random parameter Tobit approach to identify "willingness to pay among Swedish households to avoid power outages". And Flannery et al. (2009) in Ireland have used random parameter logit model to explore the participation of young people in higher education. These studies used Halton draws for the estimation of maximum likelihood, and they found that when they used random parameter models, the effect of some variables varied across the observations due to unobserved heterogeneity.

These studies illustrate the effect of random parameters count data models on accident data across the roadway segments. Previous studies mentioned in this section found that random parameters models account for unobserved heterogeneity, and statistically provide better overall fit and efficiency than the fixed parameters NB model. Thus this study (thesis) used the same approach for the prediction of total accidents, truck accidents, and HBIs at roundabouts with respect to different roundabout categories. According to previous literature, no studies on the effect of the random parameters model on total and truck accidents at roundabouts and on HBI in all type of road segments and at intersections including roundabouts have been undertaken. Thus this study represents a novel approach of the application of random parameters NB models to the prediction of accidents and HBIs at roundabouts.

2.1.6 Factors Affecting Road Accidents

There are a number of factors influencing road accidents. For example, traffic characteristics (the amount of traffic on the road, vehicle speed), road way characteristics (geometric layout of the road, including number of lanes, horizontal curve, vertical curve, section length, intersection availability, etc.), driver behaviour (age, gender, using a seat belt, drinking alcohol, using mobile phones, changing lanes, etc.) and environmental factors (lighting, weather, and road surface conditions). However, other factors influence the occurrence of accidents and relate to the mechanical properties of a vehicle: for instance, the availability of the "Antilock Braking System (ABS)", and "Electronic Stability Control (ESC)" (Rubin-Brown and Jamson, 2013, p.184-185). Previous studies have addressed many of these factors with respect to all vehicle and truck accidents. It is important to review how these factors affect road accidents in general before illustrating the characteristics of accidents in roundabouts.

Estimating the influence of roadway geometrics and traffic characteristics has been undertaken by many researchers, using NB distribution models. For instance, Ivan and O'Mara (1997) used a NB distribution to estimate the truck accident rate with respect to traffic and geometric characteristics. They stated that AADT is an exposure variable that affects truck accidents, while the influence of geometric, and speed measures was found to be insignificant. A similar study on the effect of traffic and geometric variables on the rate of accidents using NB was undertaken by Milton and Mannering (1998) and they found that as AADT increases accident rate increases. And for truck accidents Joshua and Garber (1990) and Maiou and Lum (1993) have found that as AADT per lane increases truck accident rate increases. However, Milton and Mannering (1998) have identified that accident rates decrease when the truck percentage increases for locations of greater than two-lanes, and they explained that this decrease is due to higher truck percentage relative to cars, as this affects the driver behaviour and enhances a good opportunity to pass the road safely without overtaking and lane changing and leads to lower accident rates. Similarly, the same assumption is illustrated by Miaou (1994) who stated that with a higher percentage of trucks, a lower number of vehicles will change their lane and overtake, and this leads to lower accident rate. Similar results were found by Hiselius (2004) in a study comparing the rate of accidents in homogenous in inhomogeneous traffic, using NB and Poisson regression to estimate a relationship between accident frequency with homogenous and mixed traffic. They found that accident rates decrease with an increase in the number of heavy trucks. They stated that speed reduction and the discomfort of non-truck drivers in the presence of trucks are the reasons for this decrease.

Many studies on traffic volume, such as those undertaken by Peirson et al. (1998), and Dickerson et al. (2000), estimated traffic volume as the major exposure variable influencing the rate of accidents at roadway segments, as traffic volume increases, the accidents increase. A more detailed study on the influence of traffic flow on accidents, regarding the time of the day (daytime, night-time) are undertaken by Martin (2002), who in a study on French motorways examined the correlation between accidents and traffic volume, according to whether the road was congested or not. The results reveal that more accidents are recorded in light traffic relative to heavy traffic. The author stated that daytime and night-time accidents generally are the same, but according to severity type, accidents that occurred during night-time and with low traffic volume are much worse (i.e., the number of fatalities and serious injuries during the night-time is higher than daytime). Turner and Thomas (1986) revealed that a high percentage of fatal and serious injury accidents occur during early morning with low traffic volume.

The summary of the factors influencing total and truck accidents at roadway segments is illustrated in Table 2-1.

In conclusion, from these studies the influence of traffic and geometric characteristics has been widely studied by researchers; however, each study has estimated different geometric variables related to the road network, and it can be concluded that NB models better fit accident data. Note that studies presented in this section were on road segments, so they used different geometric variables relative to this study (thesis) for instance: horizontal and vertical curvature, road segment length, gradient, shoulder width which all related to road segments rather than roundabouts.

Table 2-1 Summary of the Traffic and Geometric Variables Affecting Traffic Accidents in Previous Studies

Study	AADT	Truck traffic	Horizontal curve	Vertical curve	Section length	Lane width	Lane number	Shoulder width	Night time and day time
Mohammedshah et al. (1993)	Higher AADT higher truck accident	Higher truck AADT higher truck accident	Truck accident increase with degree of curvature	Truck accident increase with vertical gradient					
Daniel and Chien (2004)			Significant variable to be taken in to account	Significant variable to be taken in to account	As section length increases truck accident increases				
Joshua and Garber (1990)	Truck accident increase with AADT	Truck accident increase with truck percentage							
Maiou and Lum (1993)	Truck accident increase with AADT		Truck accident increase with horizontal curvature	Truck accident increase with vertical curvature	As section length increases truck accident increases				
Ivan and OMora (1997)	AADT is an important exposure positively effects truck accidents								

Table 2-1 Continued

Milton and Mannering (1998)	Accident rate increases with increasing AADT and percentage of AADT in peak hour	Accident rate decrease with increase truck percentage			Accident rate increases with increasing section length		Accident rate increases with increasing number of lanes		
Miaou (1993)		Accident rate decrease with increase truck percentage							
Hiselius (2004)			Availability of horizontal curve influence truck driver behaviour and increase truck accidents						
Peirson et al. (1998), and Dickerson et al. (2000)	As traffic volume increase accident increases								
Martin (2002)	Higher accident recorded in light traffic rather than heavy traffic								Fatalities is higher in night time rather than day time
Turner and Thomas (1986)									High percentage of fatal and serious injury during early morning

2.1.7 Summary

This section illustrated the general accident trends in the UK, EU and US as well as the main contributory factors recorded by police in the UK. In addition, accident prediction models and the methodological approach behind random-parameter models were illustrated, then the main factors influencing total and truck accidents presented. After the government set a target to reduce the number of accidents in the UK, it was successful, and by 2009 serious and fatal accidents declined by 37% and 44%, respectively; in the EU fatalities declined by 60% during a 20-year period, and in the US by 25% during a 10-year period in 2013. Training and education on the road network, and vehicle and highway technologies all influenced this decline. So there are fewer black spots, and near-miss accidents should be investigated to provide additional information to accident studies.

In the UK, the highest fatality percentage was recorded in accidents involving goods vehicles relative to other vehicle accidents, and it was found that the highest percentage of pedestrians killed were hit by trucks (DFT, 2014). In the US and in the EU the majority of fatalities involving truck accidents were non-truck drivers, 71%, and 55 to 65%, respectively. In addition, Carstensen et al. (2001) and Grygier et al. (2007) stated that when accidents occurred between trucks and other types of vehicles the majority of fatalities were passengers of other types of vehicles. Size, weight, manoeuvrability, reduced braking and truck power all influenced these accidents to be more severe. Therefore, it is important to study truck accidents.

Driver/rider behaviour is the highest contributory factor to accidents for vehicles and for trucks on the road network, while only 3% of accidents involving HGVs occurred because of sudden braking (DFT, 2014). However, accidents with other contributory causes may lead to harsh braking.

According to previous studies, Poisson and NB models best describe the relationship between truck and total accidents (count data, discrete and non-negative) with geometric and traffic variables. Joshua and Garber (1990), Mioa and Lum (1993) as well as Milton and Mannering (1998) state that the NB distribution is a good approach for analysing accidents.

Traditional Poisson and NB models explain accident prediction in detail, but assume the influence of independent variables to be fixed across the observations. Researchers (Milton et al., 2008; Anastasopoulos and Mannering, 2009; El-Basyouny and Sayed, 2009b; Granowski and Manner, 2011; Ukkusuri et al., 2011; Venkataraman et al., 2014) applied random parameters models to count data and stated that the influence of any independent variable could vary differently through the observations (in their case study, observations were of road segments or corridors). However, they concluded that statistically the random parameters model is more appropriate for predicting accident data compared to the fixed parameters model. So NB random parameter models are used in this study (thesis).

2.2 Near-Miss Accidents and HBIs

2.2.1 Overview

Near-miss accidents or near-crashes are similar to accidents, but involve different manoeuvres being taken by the driver to prevent that accident from occurring. Many factors lead drivers to experience near-miss accidents, including their behaviour, vehicles, and road environment, as well as road infrastructure. The majority of studies undertaken have addressed the influence of driver behaviour on near-miss accidents; these will be addressed in the following section. Such studies consider the main factor related to near-miss occurrences. However, braking incidents are one of the manoeuvres employed by drivers, and incidents are considered as accident near-misses in case of heavy braking (i.e., if the braking deceleration records a high “g” force); this will be discussed in the following sections. The principal aim of this section is to review previous studies undertaken on near-miss accidents and HBIs. In addition, this section will describe the decelerations that are considered as to introduce additional evidence to this study, which is mainly related to HBIs; this will benefit the interpretation of HBIs that are discussed in Chapter 3. This study is also intended to assess the research that was undertaken previously on HBIs to show that there is a lack of studies involving road traffic and geometric characteristics and their influence on HBIs.

2.2.2 Near-Miss Accidents and Factors Influencing Near-Miss Accidents

The 100-Car NDS by Dingus et al. (2006) defines a near crash or accident near-miss as, “Any circumstance that requires a rapid, evasive manoeuvre by the subject vehicle (or any other vehicle, pedestrian, cyclist, or animal) to avoid a crash”. The manoeuvre that is considered “rapid, evasive” includes “steering, braking, and accelerating”, or any other manoeuvres that are out of the control of the vehicle and driver (p.22 and also in p.68). In this manual, any rapid manoeuvre to prevent an accident to occur would be braking at >0.5 g or when lateral acceleration was higher than 0.4 g during steering. In order to convert actual “g” forces to m/s^2, the value of “g” is multiplied by the “standard value of gravitational acceleration at sea level on earth", which is 9.8 m/s^2 (Geotab Inc., 2015). In the case of 0.5 g the resulting acceleration is 4.9 m/s^2 and for 0.4 g is 3.9 m/s^2.

The 100-Car NDS defines an incident (crash relevant conflicts, and proximity conflicts) as, "Any circumstance that requires a crash-avoidance response on the part of the subject vehicle or any other vehicle, pedestrian, cyclist, or animal that is less severe than a rapid evasive manoeuvre, but greater in severity than a 'normal manoeuvre' to avoid a crash" (Klauer et al., 2010, p.13). From the two definitions, one can understand that drivers might have accidents if any of the manoeuvres that required avoiding that accident were not undertaken. There are a number of factors that influence the driver to respond to any unusual circumstances that occur on the road network and lead them either to have an accident or to avoid that accident. Researchers widely studied the influence of many factors that influence near-miss accidents or incidents. Through the analysis of near-miss accidents, which occur more frequently than accidents, one can predict and find a solution to prevent an accident from occurring. And based on these definitions the main difference between near-miss accidents and incidents is that both making a manoeuvre to prevent accidents from occurring, but the manoeuvres required for near-miss accidents is more severe relative to the manoeuvre undertaken during recorded incidents. For instance, near-miss accidents happen in a higher deceleration relative to incidents (i.e incidents occur because of an evasive manoeuvre but it is less in magnitude than near-miss accidents). Concerning driver behaviour, a number of studies have been undertaken to understand why these near-miss accidents occur, which will be addressed in the following paragraphs.

The 100-Car NDS uses a number of dependent variables to trigger accidents, near-miss accidents, or incidents. These variables are lateral acceleration $\geq$0.7 g (6.86 m/s^2), longitudinal acceleration (acceleration or deceleration $\geq$ 0.6 g (5.88 m/s^2), event button[7], forward time to collision (acceleration greater than 0.3 g), rear time to collision, and yaw rate[8]. They use main Data Acquisition System (DAS)[9] which includes a number of nodes for the purpose of collecting data. Note that within the DAS there is a node called accelerometer box, this node collects information about longitudinal and lateral acceleration of the vehicle. In the 100-Car Study undertaken by Dingus et al. (2006), 87 accidents, 1,310 near-miss

[7] "Activated by the driver by pressing a button located on the dashboard when an event occurred that he/she deemed critical" (Dingus et al., 2006, p.20).

[8] "Yaw is a measure of correction after a turn and is calculated as the Δv between an initial turn and the correction; in short, it is the g-force exerted when the vehicle swerves" (Simons-Morton, 2011, p.2363).

[9] The main Data Acquisition System (DAS) unit mounted under the "package shelf" of the trunk (Dingus et al., 2006, p.xxx).

accidents, and 8,295 incidents were recorded. Approximately 65% of accident near-misses and 80% of total accidents occurred because of the driver looking sideways rather than in front of them in the roadway before the accident occurred. The majority of incidents and near-crashes occurred during moving manoeuvres of the lead vehicle, while 100% of accidents occurred when the vehicle stopped. In this study 70% and 85% of lead vehicle near-miss accidents and incidents involved braking alone, with 18% steered right and 9% steered left. Note that 22% and 30% of near-miss accidents and incidents recorded by the lead vehicle were found to be intersection related, and 27% and 24% of near-miss accidents and incidents were recorded by the following vehicle at intersections. The rate of accidents and accident near-misses in drivers aged 18 to 20 years was four times those of drivers aged ≥ 35 years. Drowsiness caused 12% and 10% of accidents and near-accidents, respectively. For the lead vehicle, the highest incident and near-crash rates occurred at speeds of 21 to 40 mph, while the majority of the following vehicles decelerated and experienced incidents at speeds of 11 to 20 and 21 to 30 mph, respectively. The author stated that event severity increases with increasing speed. When a driver is following another vehicle and the headway distance between them is short, they will drive more carefully, and in these situations, a sudden deceleration can probably occur by the lead vehicle, which causes near-miss accidents.

Moreover, as stated by Jamson et al. (2008) in a study of developing a safety index for a database including 150 international specialists in the area of road safety and driver behaviour, the safety index declines when headway is less than 2 seconds between the two vehicles, and with less awareness when drivers change their lanes and exceed boundaries. In another naturalistic 100-car study by Klauer et al. (2006), the most sensitive safety measures for inattentive driving are average lateral acceleration (0.51g (5 m/s^2)) and maximum longitudinal deceleration (0.44 g (4.3 m/s^2)) in addition to average percentile throttle and yaw time differential.

In the 100-car NDS on the influence of lane-change on accidents and near-miss accidents undertaken by Fitch et al. (2009), they found that during the lane change manoeuvre, within a time duration of 5 seconds, four of the drivers braked at an average deceleration of 0.33 g (3.23 m/s^2), with maximum deceleration of 0.68 g (6.66 m/s^2), while twelve drivers braked and steered at an average deceleration of 0.23 g (2.25 m/s^2) and at maximum deceleration of 0.53 g (5.19 m/s^2). Additionally, the majority of drivers braked and steered left, and braked and steered right, with decelerations of 0.48 g (4.7 m/s^2) and 0.38 g (3.72 m/s^2), respectively. It is identified that a subject vehicle sideswiped by another major vehicle brakes harder to the left rather than to the right. The researchers concluded that this is due to the visibility of the subject vehicle: the driver cannot see how close he or she is to the other vehicle, when the other vehicle's location is in the right-rear region. This causes the subject vehicle to change its lane in a longer process and to require a more severe manoeuvre to prevent an accident from occurring.

Regarding the relationship between accidents and near-miss accidents, Guo et al. (2010) in a 100-car study, investigated the influence of driver behaviour and other risk factors on accidents and near-miss accidents, for the purpose of replacing near-miss accidents in an analysis of accidents, because they observed that accident numbers are small relative to near-miss accidents. They used the Poisson regression model[10] to investigate the relationship between accidents and near-miss accidents. They found that accidents increase with an increasing number of near-miss accidents. In addition, they related accidents to near-miss accidents according to gender, age group, level of service, lighting condition, road alignment, road surface condition, and near accident (Guo et al., 2010). Table 2-2 shows the adjusted R^2 value for each factor involved in an accident and the related significance of each factor. It is clear that there is a strong linear relationship between accidents and near-miss accidents based on the contributory factors included in this study. They illustrated that near-miss accidents are a good indicator for the purpose of predicting the rate of accidents. They concluded that during naturalistic studies when the number of accidents is low, it is essential to replace accidents with near-miss accidents for the purpose of safety analysis.

Guo et al. (2010) related near-miss accidents to accidents regarding a number of factors. In this study (thesis study), different factors were included so as to find the relationship between accidents and HBIs along with traffic and geometric variables using NB regression at roundabouts. It should be taken into account that in Guo et al. (2010) the study of near-miss accidents included all types of manouvres, not only harsh braking manouvres.

[10] Accident= 0.099 $*\exp^{0.21 \text{ near-miss accident}}$

Table 2-2 Relationship Between Accidents and Near-Miss Accidents Results based on Different Factors (compiled from Guo et al. , 2010)

Factor	Adjusted R^2	Significance
Gender	NA	No
Age group	0.87	No
Level of service[11]	0.33 (0.45 polynomial)	Yes
Lighting condition	0.95	No
Road alighnment (curve, striaght level)	0.99	Yes
Road surface condition (dry, icy, snowy, wet)	0.99	Yes
Weather condition (clear, cloudy, fog, mist, rainy, snowy)	0.99	No

2.2.3 Harsh Braking Incidents

HBIs, as discussed in an earlier section, are considered as near-miss accidents, according to the definition of near-miss accidents when longitudinal deceleration exceeds a rate, for instance in the 100 car study by Dingus et al. (2006) when it exceeds 0.5 g. However, a number of studies have been done on driver behaviour and the influence on braking and safety of the road network. Each study found different longitudinal decelerations to consider as harsh braking, which is illustrated in this section.

Geotag Inc. defines harsh deceleration "as acceleration greater than 4.76 m/s^2 (0.49 g) in the backward direction" (i.e, in the x-axis) in this case the driver would feel like they were thrown forward towards the steering wheel and the load in the vehicle would shift to the front of the vehicle" see Figure 2-2. A turn is defined as harsh or aggressive when the acceleration is greater than 4.76 m/s^2 in the y-axis (Geotab Inc., 2015). Note that for the vehicle the x-axis with the direction of travel refers to longitudinal acceleration and the y-axis refers to the lateral acceleration. Figure 2-3 illustrates the forces affecting a vehicle and how the braking force (in the orange bracket) is responsible for longitudinal deceleration of the vehicle.

[11] Level of service is used to evaluate traffic density in the road network. There are six levels of service starting at A for free flow condition and, ending at F for congested condition with low speed (Guo et al., 2010).

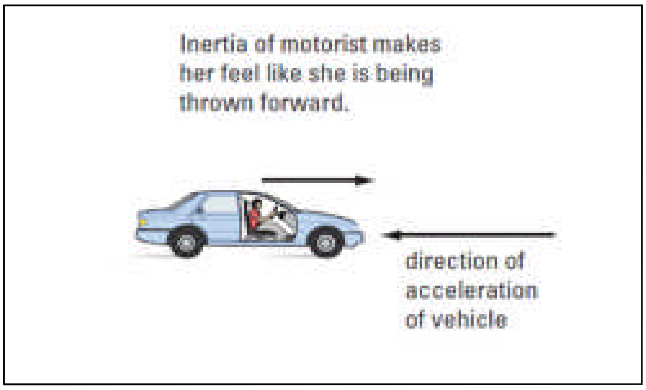


Figure 2-2 Direction of Vehicle Motion During Braking (Geotab Inc., 2015)

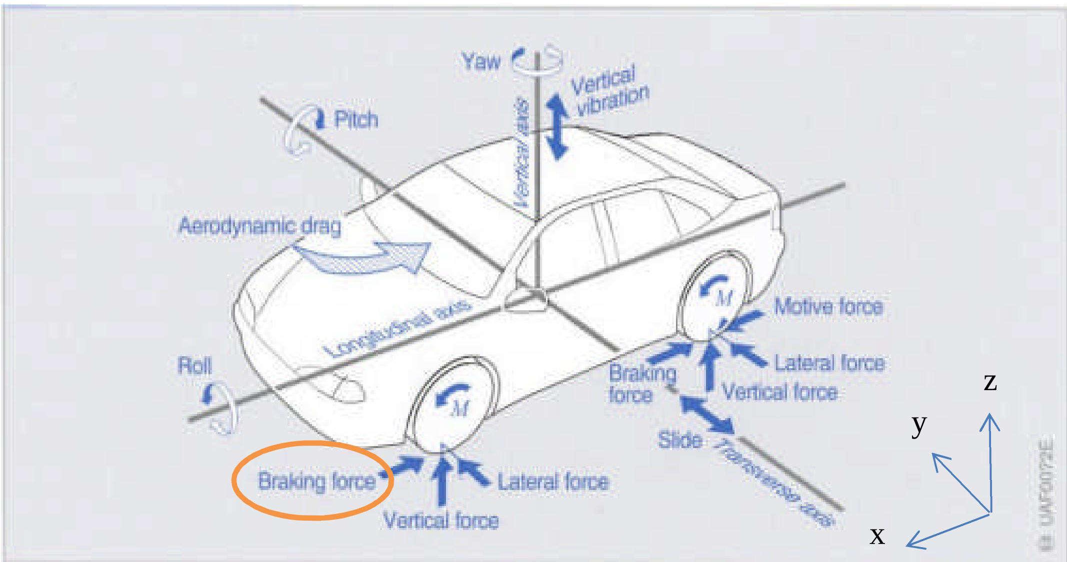


Figure 2-3 Forces Affecting a Vehicle (Andersson, 2008)

In the euroFOT project “incident is defined as harsh braking as decelerations of more than 4 m/s^2” (Kessler et al., 2012, p.20). They stated that the situation where the following vehicle brakes suddenly can be considered more interesting than a situation that occurs because a light turned red. This project is based on vehicles equipped with Advanced Driver Assistance Systems (ADAS) which is used by 1000 drivers driving in real traffic. The project aims to address a number of functions including road safety, efficiency and the environment. The drivers included in this study either owned their car or are professional drivers working for freight companies. “Forward collision warning (FCW), adaptive cruise control (ACC), speed regulation system (SRS) were used for the longitudinal control functions” (p.1). With the manoeuvre of drivers following a lead vehicle, it was found that time headway were increased for both cars and trucks, and the number of HBIs were decreased using (FCW and ACC). SRS includes speed limiter (SL) and cruise control (CC) and when SL of the vehicles was active, over speeding and HBIs was decreased. While a strong increase in over speeding was observed when CC was active; but HBIs, strong jerk[12], and critical gap acceptance were reduced.

Another definition for HBIs by Teletrac (2016) is "The number of heavy braking incidents based on G-force and type of vehicle (light, medium, or heavy)".

Oil and gas companies (OGP, 2014) use in-vehicle monitoring systems (IVMS) for the purpose of reducing accident rates and casualties among workers, defining a HBI as "an indicator of distracted or fatigued driving, the driver following too closely, or not looking far enough ahead" (p.16). The IVMS monitor continually detects deceleration at or above -6 mph/s (9.65 km/h/s), which means a harsh braking event is indicated by a deceleration of 2.68 m/s^2 (OGP, 2014).

A study on 55 trucks from 7 trucking fleets on the effect of driver distraction in operations of commercial vehicles was investigated by Olson et al. (2009) using data from Drowsy Driver Warning System Field Operational Test (DDWS FOT) and Naturalistic Truck Driving Study (NTD). DDWS FOT longitudinal deceleration (harsh braking) for trucks is triggered at any deceleration $\geq$ 0.35 g (3.43 m/s^2), and based on NTD harsh braking is triggered at longitudinal deceleration of $\geq$ 0.20 g (1.96 m/s^2). The study itself used a trigger of $\geq$ 0.20 g for HBIs. These data, collected by DAS, included video, dynamic performance and audio. Similarly, Blanco et al. (2011) in an NDS exploring the performance of 97 truck drivers identified the relationship between driving hours, working hours, and breaks with safety critical events. A trigger of >0.2 g was selected for HBIs. Safety critical event includes "crashes, near-crashes, and crash-relevant conflicts, as well as unintentional lane deviations" (p.14). It was found that the safety critical events increase with increasing driving and working hours.

A study on safe driving by Fazeen et al. (2012) using Toyota Yaris cars and mobile phone accelerometers for detecting driver safety used the y-axis with the direction of travel to detect longitudinal deceleration. The mobiles were placed in the centre console of the car, because authors stated that it gives the best data with low engine response. They found that any longitudinal deceleration of > 3 m/s^2 (>0.3g) is considered unsafe; for this study the maximum sudden deceleration was 5 m/s^2.

[12] Rate of acceleration per time

In tractor semitrailers, there is a point that should be taken into account, which is that any unbalanced braking between tractor and semitrailer leads the heavy vehicle to be unstable, and uncomfortable, and in addition, may cause accidents, for instance, jack-knifing and swing-out, and this situation arises from the point (pin) between the tractor and semitrailer, called the kingpin[13]. Heavy vehicles equipped with ABS, reduce the possibility of jack-knifing and swing-out accidents (Ruhl and Dooley-Owen, 2012). As the majority of passengers killed in accidents between heavy vehicles and passenger cars are passenger car occupants, Grygier et al. (2007) conducted a study on air disc brake effectiveness of trucks. Four manoeuvres undertaken were "right incursion, left incursion, stopping vehicle" (55 mph) the maximum deceleration rate was 0.75 g (7.35 m/s^2), and stopping vehicle[14] (70 mph). They stated that drivers that use air-disk brakes have had fewer accidents and accident casualties than drivers that used enhanced disk brakes. They concluded that a harsh braking manoeuvre within a shorter distance reduces accidents and accident severities. These characteristics show the mechanical problems within the heavy vehicle in addition to driver behaviour, and their influence on braking leads them to have different types of accidents that are common in heavy vehicles such as jack-knifing and swing-out.

Benmimoun et al. (2011) in the EuroFot project, using vehicle CAN[15], categorised incidents with regard to "vehicle dynamics" and "distance behaviour". In the category of "vehicle dynamics" the incidents are based on two deceleration levels, level 1 (low threshold), with deceleration of greater than 6 m/s^2 at a speed of less than 50 km/h for cars and a deceleration of greater than 6 m/s^2 for trucks, and when speed is between 50 and 150 km/h the deceleration decreases to 4 m/s^2 for cars and trucks. The second level (high threshold) detected at higher decelerations, when deceleration exceeds 8 m/s^2 and 7 m/s^2, for cars and trucks, respectively, records incident level 2 and does not depend on speed. However, regarding the second category, "distance behaviour", there are two levels, in this category incidents were recorded at a speed of 30 km/h. Incidents were recorded and considered as

[13] "Kingpin: "The pin on a trailer that connects it to the fifth wheel of the tractor" (Vehicle Valuation Services Inc, 2000, p. 70)

[14] This event is based on forcing the driver of the lead truck to react to the obscured and stopped vehicle on the roads while travelling at 55mph and at 70 mph (Grygier et al., 2007).

[15] The Controller Area Network (CAN) was developed by Robert Bosch GmbH for automotive applications. "Typically, CAN interconnects a network of modules (or nodes) using two wire, twisted pair cable. CAN is a serial, multimaster, multicast protocol, which means that when the bus is free, any node can send a message (multimaster), and all nodes may receive and act on the message (multicast). The node that initiates the message is called the transmitter; any node not sending a message is called a receiver" (Cook and Freudenberg, 2007, p.2).

level 1 when the the time headway was ≤0.4 s, then considered as level 2 at >0.4s, and the driver starting a harsh braking had a maximum value of 6.9 m/s^2.

However, more studies were undertaken on HBIs and driver behaviour using passenger cars as illustrated in the following paragrphs:

A recent study on distracted driving at single-lane roundabouts by Haque et al. (2016) found that at roundabout entry an average deceleration of 4.43 m/s^2 was recorded when drivers are not involved in a phone conversation. Higher decelerations were recorded by drivers using hand-held devices (4.96 m/s^2) and hands-free devices (5.15 m/s^2). This indicates that being distracted increases the deceleration rate. In this study CARRS-Q Advanced Driving Simulator was used to test 32 drivers of passenger cars on a simulated scenario called gap acceptance. They concluded that hard braking leads distracted drivers to have rear-end accidents with the following vehicles. Another study on driver behaviour at roundabouts by Qian et al. (2015) using Advanced Surveying technology and GPS system investigated positioning eye fixation and vehicle movement in a naturalistic driving study for assessment of driver behaviour. Speed of vehicle, longitudinal and lateral position data were used. They found that while approaching the roundabout drivers reduce their speed from 40 to 21-30 km/h, then to 11-20 km/h while they are entering the roundabout. This study was undertaken by five older drivers (aged 60 to 79) and the results indicated that these drivers' manoeuvres through the roundabouts were at higher average speed, had a better gaze looking strategy and less lane changing compared to younger drivers.

A naturalistic study on "harsh braking events among novice teenage drivers by passenger characteristics" was undertaken by Simons-Morton et al. (2009). This study included 42 teenage drivers who had recorded HBIs at ≤ -0.45 g (4.41 m/s^2). They recorded 1721 HBIs and stated that they happen because of driver misjudgement (79.1%), driver behaviour (10.8%), manoeuvrability (5.3%), and driver distraction (4.8%). The rate of harsh braking among new, teenage drivers was higher than for adult drivers. They concluded that it is true that the high driving risk is associated more with teen drivers and this rate increases when teen drivers carry other teenagers, than when driving alone or carrying an adult.

Another study on the understanding of vehicle characteristics and driver responses was undertaken by Bayan et al. (2009). The braking of trailers was tested on wet and dry surface conditions at 30 mph and 60 mph. They recorded three different manoeuvres. The first one was 60 mph dry braking in a straight line, and the maximum deceleration recorded in this manoeuvre was 0.75 g (7.35 m/s^2); the second manoeuvre was 30 mph dry braking in a straight line, and the maximum deceleration recorded in this manoeuvre was 0.72 g (7.06

m/s^2); finally, 30 mph wet braking on a curve was performed and the maximum deceleration recorded was 0.51 g (5 m/s^2). Another study on vehicle performance on dry and wet pavement was undertaken by Greibe (2007) in "braking distance, friction, and behaviour" and identified that for dry and wet surface conditions, the average deceleration value for braking is 8.4 m/s^2 and 7.9 m/s^2 for experienced drivers using passenger cars, respectively. In this study, an inexperienced driver using passenger cars recorded braking at average deceleration of 7.4 m/s^2 on dry surface conditions, and at 7.0 m/s^2 on wet surface conditions. They stated that these rates are 10% less than for experienced drivers. In this study, they found that the mean deceleration for comfort braking is 3.2 m/s^2; they stated that the (AASHTO) green book recommends a deceleration of 3.4 m/s^2 for comfort braking.

A road assessment study on distraction and its influence on driver vision behaviour and braking performance were undertaken by Harbluk et al. (2007). The study was of 21 drivers on 8 km road segments (4 km divided road) and the speed limit on that road was 50 km/h. In this study, they stated that braking was considered harsh at a longitudinal deceleration of greater than 0.25 g (2.45 m/s^2). They found that 85% of harsh braking occurred at signalised intersections. They stated that HBIs increase with lower visual performance, including looking at objects inside and outside the car, looking at the mirrors of the cars, and looking at the traffic signals and any other visual environment conditions.

Another study at intersections by Lee et al. (2007), in a 100-car naturalistic driving study for promoting braking sign performance and functions, investigated 50 intersections and found 32 near crashes were recorded at a deceleration of 0.66 g, 320 incidents were recorded at a deceleration of 0.51 g, and only 1 accident was recorded at a deceleration of 2.7 g. They related near accident and incident to weather conditions, lighting conditions, traffic congestion, traffic lanes, alignment, and driver seat belt use. The majority of incidents and near-miss accidents occurred in clear weather and daylight conditions, however, more near crashes were recorded in rainy weather and night-time, relative to incidents. No relationship was identified between number of traffic lanes and incidents and near-miss accidents. Forty-five per cent and 50% of near-miss accidents and incidents, respectively, were recorded in traffic congestion. It was found that 94% of incidents occured on a straight road and only 5% occurred on a curve, while 16% of near crashes occurred on a curve with 84% on a straight road. They stated that 30% and 15% of near-miss accidents and incidents, respectively, were recorded when drivers were not using their seat belt. They concluded that incidents are not a good indicator of accidents, while near-miss accidents are more related to accidents.

A simulation study by Inman et al. (2006) was done at intersections compared to a real study test track, “to evaluate the feasibility of warning potential victims of read-light violators”. In the simulation study, drivers who could not catch a green light at the intersection braked at a maximum deceleration of 0.78 g from a distance of 55 m over a 1 s period, while a lower rate of maximum deceleration of o.67 g was recorded with a real study (test track). They stated that at an intersection, most of the drivers braked harshly when they received a clear infrastructure warning. Moreover, they stated that this would help them to prevent accidents caused by “red-light violators”.

Klauer et al. (2009) used a 100-car study base data to compare the performance of drivers who recorded a high number of accidents and near-miss accidents to drivers who recorded fewer of both events. They indicated that manoeuvres including higher heavy deceleration, acceleration and swerving are performed more by unsafe drivers than safe drivers. They stated that the risk of accidents increased due to inadequate speed and inappropriate braking (which constitutes 3566 risky driving behaviour out of a total of 7351 events), which they considered as serious driver behaviour. They also found that in traffic congestion during restrained speed, drivers are more involved in serious driving behaviour than the situation of low flow and unrestrained speed. They concluded that drivers who were involved in unsafe driving usually record incidents at a deceleration of >0.3 g. However, in this study, they found that experienced drivers are more involved in safe driving than the drivers who have fewer years of experience.

2.2.4 Summary and Conclusions

As discussed in this section, a near-miss accident is a condition that needs a rapid manoeuvre and/or braking by the driver to prevent an accident from occurring. According to the 100-car naturalistic driving study, braking at >0.5 g is considered as a rapid evasive manoeuvre although other authors set the safe deceleration as low as 0.3g.

A number of studies investigated near-miss accidents and their relationship with accidents, for instance Guo et al. (2010) using Poisson regression found that near-miss accidents are highly related to accidents, in which as near-misses increases do accidents, and Guo et al. (2010) stated that near-misses can be used as an accident replacement when the number of accidents is low on the road network. Near-miss accidents were related to factors at an intersection, such as weather and lighting conditions, traffic congestion, traffic lanes, and alignment, as studied by Lee et al. (2007).

Different definitions are available for harsh braking events, but mainly any manoeuvre, requiring a heavy deceleration is recorded as a harsh braking event. Researchers have used different deceleration levels to trigger harsh braking events. The oil and gas company consider for their vehicles any deceleration in speed of ≥ 6 mph in one second to be harsh braking. And Blanco et al. (2011) and NTD for trucks considers harsh braking to be triggered at deceleration of > 0.20 g, DDWS Fot considers a HBI to be triggered at 0.35 g (Olson et al. , 2009). The summary of harsh braking decelerations is shown in Table 2-3.

Mechanical problems with trucks including efficiency of the brakes and truck driver behaviour, lead truck drivers to record swing-out and jack-knifing accidents as stated by Ruhl and Dooley-Owen (2012).

According to the studies illustrated in this section, the following factors lead vehicles to harsh braking:

- Driver behaviour (looking at the other side of the road rather than in front of them, and manoeuvre of the lead vehicle)
- Vehicle speed since higher braking is recorded at speeds greater than the speed limit, and braking occurs because the lead vehicle lowered its speed.
- If the headway was close between the lead vehicle and the following vehicle
- Driver inattention and vision environment
- During lane changes (cutting in from adjacent lanes)
- Driver misjudgement
- Driving experience (braking rate is higher for new drivers when it is compared to experienced drivers)
- Using hand-held or hands free mobile phones
- Intersection availability

It should be taken into account that these studies explored near-miss accidents and included all types of manoeuvres, not only harsh braking manoeuvres and that some of these studies were conducted in signalised intersections and the majority of them in road sections, not at roundabouts. It can be concluded that in this thesis, factors different from those mentioned previously were included in order to identify the relationship between accidents and HBIs.

Table 2-3 Summary of the Deceleration Level by Previous Studies for Triggering Harsh Braking Event

Study	Longitudinal Deceleration*	Notes
Dingus et al. (2006)	>0.5 g	In addition to this deceleration they used a longitudinal deceleration as dependent variables to trigger near-miss accidents at >0.6 g
Klauer et al. (2006)	0.44 g	Inattention driving are the cause for these decelerations occurrence
Fitch et al. (2009)	0.53 g and 0.68 g	During lane changes, four drivers braked at 0.68 g, and 12 drivers braked at 0.53 g
Geotab Inc., 2015	>0.49 g	Straight and turn harsh deceleration
Kessler et al. (2012)	>0.4 g	euroFOT poject
Olson et al. (2009)	>0.35 g and >0.2g	For DDWS FOT and NTD, respectively.
Blanco et al. (2011)	>0.2 g	For 97 trucks and safety critical events increase with increasing driving and working hours
Fazeen et al. (2012)	>0.3 g	This study used phone accelerometer within the cars
Grygier et al. (2007)	0.75 g	For the stopping vehicle (truck) manoeuvre with speed 55 mph
Haque et al. (2016)	0.45 g, 0.5 g, and 0.52 g	For no phone, hande-held, phone and hands-freee conversation at single lane roundabouts
Simons-Morton et al. (2009)	≤0.45 g	The majority of this braking occurred because of driver misjudgement
Harbluk et al. (2007)	>0.25 g	85% of the braking recorded at an intersection
Bayan et al. (2009)	0.75 g, 0.72 g, and 0.52 g	These decelerations are recorded in dry surface condition speed 60 mph, in dry surface condition speed 30 mph, and on wet surface condition speed 30 mph, respectively
Greibe (2007)	0.86 g and 0.81 g	This deceleration recorded in dry and wet surface conditions, resepectively.
	0.75 g and 0.71 g	This deceleration recorded for experienced driver on dry and wet surface respectively, and inexperienced brakes by less than 10% the experienced driver
Lee et al. (2007)	0.51 g and 0.66 g	At intersections the deceleration rate was for incident and near-miss accidents, respectively.
Inman et al. (2006)	0.78 g and 0.67 g	At an intersection for simulation and test track study, respectively
Klauer et al. (2009)	>0.3 g	Different braking decelerations recorded in this study and all of them were catagorised as safe, moderately safe and unsafe driving in different ranges of deceleration. Highest near-miss accidents occurred because of inappropiate braking and speed
Benmimoun et al. (2011)	0.61 g	For cars and trucks, respectively, with regard to vehicle dynamics and at a low threshold at speed < 50 km/h
	0.41 g	For cars and trucks, respectively, with regard to vehicle dynamics and at a low threshold at speed 50 to 150 km/h
	0.82 g and 0.71 g	For cars and trucks with respect to vehicle dynamics and at a high threshold
	0.70 g	For cars and trucks with respect to the distance behaviour according to a high threshold

*multiply by 9.81 to convert it to m/s^2

2.3 Safety at Roundabouts

2.3.1 Overview

Roundabouts have become popular in developed countries; in the UK roundabouts are widely used instead of other junction types. Roundabouts are considered safer than other intersection types because the number of conflicting point's decreases, which leads drivers to reduce their speeds, regulates turning movement of other vehicles, and are considered to givebetter operational performance (Kennedy, 2007; DMRB TD 16/07, 2007). However, these characteristics do not prevent accidents from occurring, as a number of all vehicle and truck accidents are recorded at roundabouts. As discussed in earlier sections, size, weight and manoeuvring of a truck is different from passenger cars, and it is essential to consider their safety at roundabouts. The principal aim of this section is to explore the general truck and total accident trends at roundabouts, and to provide a review of the literature available on the main factors influencing accidents at roundabouts. This will help with the interpretation of the models developed in this study. A summary of findings is presented in the final section, in addition to a discussion of the thesis aim and factors that are considered in this thesis.

2.3.2 Roundabout Categories

In the UK roundabouts are designed according to standards in the Design Manual for Roads and Bridges (DMRB) TD 16/07, 2007). The types of roundabouts presented in this manual are: (i) normal roundabouts that usually have a central island diameter of ≤4 m, and approaches are either single or dual carriageway; (ii) compact roundabouts: each arm of this type of roundabout has single lane entries and exits at approaches, and their design will be similar to normal roundabouts when the approaching speed limit exceeds 40 mph, but the single lane entry and exit will be kept; (iii) mini-roundabouts that do not have a restricted central island, and their diameter is small, varying from 1 to 4 metres; (iv) grade-separated roundabouts: this roundabout is usually located on motorways and has at least one approach using from a different road level; (v) signalised roundabouts: when a traffic signal is installed in the approaches or on the circulatory lanes, the roundabout becomes a signalised roundabout; and (vi) double roundabouts: two roundabouts separated by a short distance (DMRB TD 16/07, 2007). In the UK, the recommended number of arms is three or four but more than four arms is relatively common. According to the UK guidelines, roundabouts are either single-lane (single lane at entry, exit and circulatory), double-lane (double lane at entry, exit and in the circle, two vehicles can drive beside each other) or three-lane (three-lane at entry, exit and circulatory) on all arms. Two typical UK at-grade and grade-separated roundabouts areshown in Figure 2-4.

Figure 2-4 Aerial Photo of Four-Arm Grade-Separated Roundabout (Left), and Aerial Photo of Three-Arm At-Grade Roundabout (Right)

In this study a number of roundabouts have been studied that constitute three, four, five and six-arms, and they are at-grade and grade-separated, double, or triple roundabouts; they are signalised, partially signalised, or un-signalised. More details are presented in Chapter Three.

2.3.3 Geometric Characteristics of the Roundabouts

Geometric layout, operational analysis, and safety evaluation are significant requirements for the roundabout design process. Small modifications in geometry can lead to considerable changes in the safety and/or operational performance of roundabouts. Entry width is considered to be the most sensitive geometric variable associated with roundabout design. The roundabout safety decreases with increasing entry width (Retting, 2006). Table 2-4 shows the relationship between roundabout geometry and safety (Retting, 2006), and Figure 2-5 shows the roundabout geometric information.

Design for Roads and Bridges TD 16/07 (2007) illustrates that design year traffic flow is considered (e.g. the need for higher entry widths for the future) when designing new roundabouts, but when the roundabout is constructed for the early year of service it may be necessary for the designer to consider a temporary stage with lower entry width and entry lanes, achieved physically by surface colouring or hatched markings. Based on DMRB TD 16/07 (2007) the maximum entry width for multi-lane roundabouts is 15 m, because higher entry width associated with higher traffic volume as stated by Kimber (1980).

Table 2-4 Effects of Design Elements on Safety of Roundabouts (Retting, 2006)

Design element	Safety consideration
Wider entry	Less safe
Wider circulatory carriageway	Less safe
Larger entry radius	Neutral
Large ICD	Less safe
Larger angle between entries (90 degrees optimal)	Safer
Smaller entry angle 20 is minimum value	Poorer sight lines
Longer flare length	Neutral

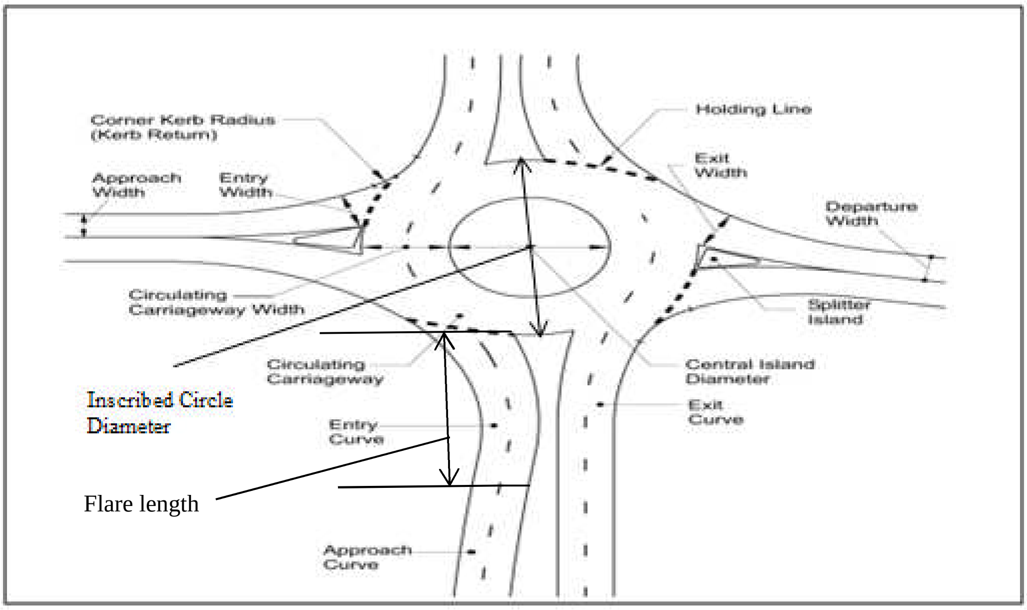


Figure 2-5 Geometric Element of Roundabout (ICD, and Flare Length Added) (Department of Main Roads, 2006)

Regarding inscribed circle diameter (ICD), if a roundabout is at-grade, ICD should not be >100 m (DMRB TD 16/07, 2007), because high ICD can lead drivers to drive at a speed of greater than 30 mph within circulatory lanes. For grade-separated roundabouts it is usual that ICD is greater than 100 m, but this result in high circulating speed, which produces difficulties in operation. To avoid this problem in the design of new roundabouts, the use of a bridge with a roundabout at each end is recommended (DMRB TD 16/07, 2007). However, for in-service roundabouts having accidents because of high ICD (on large roundabouts), signalisation is required (DMRB TD 16/07, 2007).

According to DMRB TD 16/07 (2007), the circulatory roadway width must be 1 to 1.2 times the maximum entry width. For large roundabouts the width of the circulatory lane can be reduced by adding a kerb to a splitter island; also this decrease can be achieved physically using coloured surfacing or hatched marking. Another geometric parameter that can be used within the small roundabout is a truck apron, which is "an over run area (a raised low profile area around the central island)" important for trucks using small roundabouts (DMRB TD 16/07, 2007, p.7/4). Gingich and Waddell (2008), in a study of a roundabout during morning and evening peaks, recorded that 624 trucks travelled within the roundabouts, 77% of which did not use truck apron, and of those that did, 67% did so to prevent other cars in the adjacent lane from travelling beside them.

2.3.4 Road Marking and Shape of the Central Island

For a well-designed roundabout with a balanced traffic movement and efficient operations, no additional road markings at approaches and within the circulatory carriageway are required. For in-service roundabouts where traffic volume has changed since design, road marking is considered to be an important factor affecting safety and capacity. When the circulatory carriageway is wide, this may confuse drivers if there is no marking. Weber et al. (2009) indicated that bigger roundabouts are better for trucks and other large vehicles. They stated that the use of road markings within the circulatory makes the roundabout bigger, which they found safer for truck drivers, as they can stay in their own lane. Regarding safety, using road markings at roundabouts will reduce three types of accidents: "side to side collisions on the circulatory lanes, drivers being forced on to the central island, and collisions between entering and circulating vehicles" (DMRB TA 78/97, 1997, p.2/1). Adding markings leads drivers to choose the right path, which can decrease the chance of conflicting within the circulatory lanes that are wide. Using road markings within the circulatory lanes at grade-separated roundabouts increases the efficient use of the circulatory lanes, as drivers can choose the right path (DMRB TD 16/07, 2007). According to DMRB TA 78/97 (1997) there are four types of markings: concentric, partial concentric (for wide circulatory width), concentric-spiral, and spiral (more suitable for large roundabouts).

Regarding the shape of the central island, the majority of the roundabout design guidelines advise the use of circular roundabouts, because the majority of intersections converted to non-circular roundabouts have bad accident records (Kennedy, 2007). Alphand et al. (1991, cited in Kennedy, 2007) illustrated that oval roundabouts have higher accident rates than circular ones, however Rodegerdts et al. (2010) reached the conclusion that the latter are safer because they enhance a constant speed with the circulatory lanes, while oval roundabouts increase speed in a straight line then induce speed decrease while the vehicle approaches the arc, which precipitates loss of control accidents within circulatory lanes.

2.3.5 General Roundabout Accident Trends

The principal aim of this section is to provide a review of general accident trends in the UK and other developed countries, and to indicate that roundabouts are safer relative to other intersection types by providing a number of reviews to support this statement. It is important to explore if previous findings presented in Section 2.1.2 for general accident trends at road segments are in line with general accident trends at roundabouts, which brings support to the general thesis problem statement. In addition, this section will provide information that can be used for the interpretation of accident trends at roundabouts in Chapter Four.

Previous studies noted that fatal accidents were reduced at roundabouts compared with other types of junctions. Regarding the safety of roundabouts, a number of studies have been undertaken concerning “before and after” (changing intersections to roundabouts). Jacquaemart (1998) stated that accidents decreased by more than 37% and injury accidents declined by 51% when intersections were changed to roundabouts. The same result was identified by Elvik (2003); however Elvik stated that this decline depends on the number of arms, as this effect in four-arm roundabouts is higher relative to three-arm roundabouts. Furthermore, Retting et al. (2001) stated that when intersections are converted to roundabouts, total accidents declined by 38% and the number of casualties declined by 76%. Similarly, Persaud et al. (2001) found the same result for 11 roundabouts converted from signalised intersections, and Rodegerdts et al. (2007) indicated that accident number and accident severity decreased by 48% and 78% in a study of nine roundabouts that were already converted. Additionally, Garder (1998) in a before and after study for Australia, France, Germany and the UK found that total accidents decreased by 35 to 61% and injury accidents by 25 to 87%. Isbrands (2009), in a study for 17 roundabouts, concluded that when intersections were converted to roundabouts, the number of accidents declined for most of the roundabouts.

These studies have shown that the number of accidents and casualty severity decreased when intersections were converted to roundabouts, but this does not mean that they are considered as the safest most of the road network, as a number of studies have been carried out on the safety of roundabouts, and a number of accidents and severities were recorded, as illustrated in the following paragraphs.

Maycock and Hall (1984) studied accidents at four-arm roundabouts for five years (1974–1979). Overall, 1427 casualties were recorded throughout the study, and 16% of these were fatalities and serious injuries. In their study, the accident rate[16] decreased by the year across their study period from 0.87 to 0.82, while in between, there was a fluctuation in this rate, which varied from 1.05 to 0.99. October has shown the highest rate of accidents[17] (1.29) followed by November (1.25) and December (1.11). April shows the lowest rate of accidents (0.70). When the ratio of accidents in a specific day is divided by the average of all days, Friday has the highest rate (1.03) followed by Wednesday (1.02) and Saturday (1.01). Sunday showed the lowest rate (0.97). Two peak periods were identified during the morning (6–10:00 am) and evening (2–6:00 pm); however, evenings showed the highest percentage of accidents (28.7%) compared to mornings (17.4%). At all roundabouts HGVs are involved in 6 to 8% of all accidents.

Harper and Dunn (2003) conducted a study of 95 urban roundabouts in New Zealand (NZ) for a period of five years (1998–2002). The roundabouts constitute 14 three-arm, 75 four-arm, 5 five-arm, and 1 six-arm, and a total of 242 accidents were recorded in the selected locations. They stated that multi-lane roundabouts are more dangerous than single lane roundabouts, because the accident rate (accident/year) at single lanes was 0.42 while at two-lanes was 0.79. They found that the rate of accident severity (fatality and serious injury) decreases with an increasing number of lanes as 8% of fatal and serious injury accidents were recorded at two-lanes with 15% at one lane roundabouts. Regarding the surface condition, 24% of accidents occurred in wet surface conditions, and 25% occurred during the night. Similar to Maycock and Hall (1984), HGVs are involved in 6% of accidents, and this is considered a steady rate.

Kennedy (2007) compared a study of 1162 roundabouts over a five-year period (1999–2003) in the UK with other countries. The sample included 326 three-arm, 649 four-arms, 157 five-

[16] Accident rate = accident frequency in a year/ average for 1974 to 1979 (Maycock and Hall, (1984)).
[17] The month accident rate is the frequency of accidents for a particular month divided by the average of all months (Maycock and Hall, (1984)).

arm, and 30 six-arm with single and dual carriageway and grade-separated roundabouts. Three-arms showed the highest accident severity (% of fatalities and serious injury) which was 9.3%, whereas 7.1% of severities were recorded at four- and five-arm roundabouts. At all roads accident frequency (accident frequency by severity/year) varies from 0.79 at three-arms to 5.95 at six-arm roundabouts. This shows that as the number of arms increases, the rate of accidents increases. In Kennedy's (2007) study, LGVs and HGVs were involved in 6.4% and 9.3%, of accident casualties, respectively, which is close to the rate identified by Maycock and Hall (1984) and Harper and Dunn (2003) for HGVs, while cars and taxis were involved in 76% of the accident casualties. From 1999 to 2003, accidents have decreased by 6.84% (see Figure 2-6), which is in line with previous studies illustrated in Section 2.1.1, illustrating that accident trends decrease. Regarding the number of accidents by day of the week, weekdays accounted for a higher number of accidents compared to weekends and similar to Maycock and Hall (1984) Friday had the highest rate (1.11), whereas Sunday accounted for the lowest rate (0.82). May to December records the highest accident rate relative to January to April, and November accounted for the highest rate (1.12), whereas March records the lowest rate (0.87). According to the time of day, the highest rate was recorded from 8:00 to 10:00 in the morning (1.55), 12:00 to 14:00 in afternoons (1.61), and 16:00 to 18:00 in the evening (2.03). These peak periods were found to be different from the study of Maycock and Hall (1984), the probable reason being that each study was performed in different periods and traffic volume changes yearly, so this might be the cause of these differences. In this study, the rate of accidents in dual carriageways was 2.6 per year which was higher than the rate in single carriageways (1). However, more fatalities and serious injuries were recorded in single carriageways (8.7%), relative to dual carriageways (6.9%)—similar findings to those of Harper and Dunn (2003).

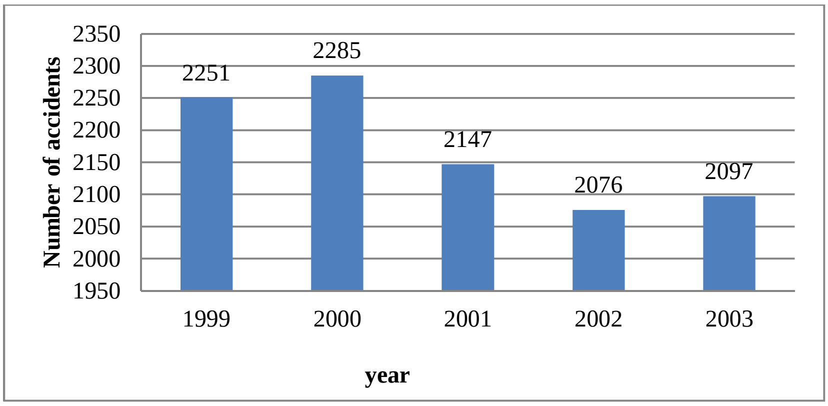


Figure 2-6 Accident Number by Year (1999–2003) (compiled from Kennedy, 2007)

From the studies discussed in this section, it can be noted that cars are more involved in accidents than trucks because traffic volume on the roads is mainly cars, and trucks make up a small percentage of traffic. However, Kennedy (2007) shows that trucks are more dangerous than cars because the percentage of fatalities and serious injuries in LGVs and HGVs together are 13.6% (8% HGVs+5.6% LGVs), while 6% of fatalities and serious injuries were recorded for car accidents. This shows that more people are killed or seriously injured because of trucks, which is in line with other studies (DFT, 2014; Trucks V, 2013; US Department of Transportation, 2014; Carstensen et al., 2001; Grygier et al., 2007) (illustrated in Section 2.2.1).

2.3.6 Relationship Between Roundabout Traffic and Geometric Characteristics with Accident Rates

The influence of geometric and traffic variables on total accidents using different models at roundabouts has been widely addressed by researchers. The principal aim of this section is to explore the work undertaken previously, what models they used and the influence of each geometric and traffic characteristic on safety and performance of roundabouts. In addition, a comparison of their findings with the thesis findings is presented in Chapter Five. The following subsections presents the flow-only model and flow geometric model, then a summary of the models identified from both type of the estimated models is presented in the flow-geometric model section as a table.

2.3.6.1 Flow-Only Model

Traffic volume is the main exposure variable influencing (mainly increasing) the number of accidents as shown by many researchers, which will be addressed in this section. In addition, the Highway Safety Manual (HSM)[18] uses traffic volume as a major input into the safety performance functions. Roundabouts, as substitute intersections, are therefore likely to have a similar traffic volume influence on anticipated safety performance (AASHTO, 2014).

In the Maycock and Hall (1984) study, using NB and Poisson regression models, they analysed accidents on 84 four-arm roundabouts in the UK using different geometric and

[18] $N_{SPFrs} = AADT \times L \times 365 \times 10^{-6} \times e^{-0.312}$

Where $N_{SPF\,rs}$ is estimate of predicted average crash frequency for safety performance function (SPF) base conditions for a rural two-lane two-way roadway segment (crashes/year); AADT is average annual daily traffic volume (vehicles per day) on roadway segment; L is length of roadway segment (miles) (AASHTO, 2014, p.3-16).

traffic volume variables. They built two different models: flow-only model and a flow-geometric model, and the results showed that flow is the major variable influencing the rate of accidents. Another flow-only model was estimated using a NB model by Guichet (1997) on 12,000 roundabouts in France and traffic volume was found to have a highly significant effect on increasing accident rate. In Italy, Montella (2007), in a study on applying a NB model on accident rates at 15 urban roundabouts (55 approaches) of three- and four-arm types, found that accident rates increase with increasing traffic volume. In this study it was found that 65% of accidents occurred at roundabout approaches, with 15% and 20% in the circulatory and exit lanes, respectively.

A study on predicting truck accidents by Daniels et al. (2010) in a study for 90 roundabouts in Flanders, Belgium, was carried out during the years 1994 and 2000. This study includes a number of geometric parameters such as central island diameter, arm numbers, lane numbers, apron width, an indicator regarding if there was an intersection before the construction of the roundabout and ICD; and the study included average daily traffic (ADT) as traffic characteristics using Poisson log linear regression for the model estimation. They suggested that one of the most important factors that influence the safety performance of traffic facilities is the entering traffic volume. They built a model for HGVs, and found that average daily traffic (ADT) is the major factor increasing truck accidents at roundabouts.

However, predicting a model on only one variable may lead the estimated model to be biased and possible wrong conclusions could be drawn. For this reason, studies included geometric variables to the model in addition to traffic variables and are discussed in the following section.

2.3.6.2 Flow-Geometric Model

A number of studies have been done regarding the effects of traffic and geometric characteristics on total accidents. Some developed a flow only model as discussed in the previous section, while others suggested that adding geometric variables will increase the accuracy of the predictive models, so they predicted flow-geometric models, and others built both types of models. For instance, Harper and Dunn (2005) studied the influence of geometric and traffic volume variables on accident rates at 95 urban roundabouts in New Zealand using Poisson and NB regression models. They stated that a model including geometric parameters in addition to traffic variables has higher accuracy and the predicted equation improved. The result of this study shows that traffic volume and circulatory roadway width are the more significant variables increasing the frequency of accidents. In the

Maycock and Hall (1984) study, while considered the flow-geometric model, it was found that traffic flow (AADT), entry curve radius and entry width had a significant influence on the accident rates at roundabouts (entering/circulating), whereas at approaches it was found that the accident rate decreased with increasing entry width. They found that there was a minor effect between roundabout accidents and the angle between entry arms and the gradient. They stated that the ICD has no effect on accident rates, but when the proportion of the ICD to the central island diameter is included in the model, its effect was significant on increasing accident rates. In the Daniels et al. (2010) study, the ICD, central island diameter, width of approach, and number of lanes were found to have no effect on the number of all accidents and on the heavy vehicle accidents. However, they found that three-arm roundabouts have a positive influence on multiple-vehicle accidents and moped accidents, while this effect was found to be insignificant for total and heavy vehicle accidents.

Rodegerdts et al. (2007) found that traffic volume highly influences entering/circulating, exiting/circulating, and approach accidents; in addition they indicated that approach accidents increase with the width of the approach. They also found that entering/circulating accident rate increases with increasing entry width, while exiting/circulating accident rates increases with increasing ICD and circulatory roadway width. In addition, in Table 2-4 Retting (2006) states that with a wider entry, wider circulatory roadway and larger ICD, roundabouts will be less safe. Another study on the effect of geometric variables on accident number done by Kim et al. (2013) investigated the influence of geometric variables on 33 approach accidents (nine roundabouts) in South Korea using Poisson and NB models. Their result indicates the number of accidents increase with increasing arm number, entry lane, entry width, flare width, and number of lanes within the circulatory, while the number of accidents decreased with circulating lane width. However, the influence of traffic and geometric characteristics in a before and after study was addressed by Shadpour (2012) who investigated the safety effects of 15 roundabouts in Franklin Boulevard in Cambridge (Canada) from 2007 to 2010. The author used an OLS regression for the model estimation. When they related AADT to the number of accidents, it was found that as AADT increases the number of accidents increase. The author concluded that the geometric characteristics, lane number, and arm number have the main effect on increasing the number of accidents. The author stated that this is due to the conflict points, because multi-lane and four-arm roundabouts have higher conflict points than single-lane and three-arm roundabouts.

In this thesis speed will not be included as a variable in addition to flow and geometric variables because of the unavailability of the data, but some studies identified that speed of the vehicle is highly related to accident rates and geometric design of roundabouts is highly associated with speed of vehicle. For instance, Arndt (1998) studied the “relationship between roundabout geometry and accident rates” using linear regression models. The study included 100 roundabouts in urban and rural roads of Australia for five years (beginning of 1986 to end of 1990). The author found that traffic volume and the speed of the vehicle was highly and positively related to accident rate and stated that the speed between entering and circulating vehicles can be reduced by decreasing entry, exit, and roadway circulatory width, and by increasing the width of splitter islands. In addition, a smaller ICD will help to maintain lower speeds and hence, provide safety for roundabouts. He stated that high speed environment areas require a larger ICD. However, Austroads (1993) states that single vehicle accidents and loss-of-load incidents for trucks increased with extreme negative super elevation especially when speeds are high. Kennedy (2007) stated that it is possible to reduce truck rollover accidents by lowering the speed of the roundabout approach and the roundabout should not have any sudden changes in its geometry. Turner et al. (2006) conducted a study in Austria on predicting accidents using the NB model at 104 roundabouts of single and two-lane including three-, four- and five-arms. Accident data was from January 2001 to December 2005. They found that when the speed of circulating vehicles was reduced by 20% entering-circulating accidents were reduced by 38%. Also, reducing the approach sight distance is beneficial for reducing accidents. The models estimated for all accidents show that roundabouts with multiple entry lanes have a higher number of accidents. However, for all types of accidents they found that traffic volume has a high influence on increasing the number of accidents.

The effect of speed as a traffic characteristic and the influence of multi-lane and single-lane roundabouts on accident occurrences were addressed by other researchers. Šenk and Ambros (2011) did a study on 90 roundabout intersections in the Czech Republic for two years (2009–2010) using NB models. They studied the influence of traffic volume, the number of lanes, vehicle speed, and weather conditions on the frequency of accidents. In their study, it was found that 2-lane roundabouts are of poor quality (higher accident frequency) compared to single lane roundabouts. They found that urban areas are safer than rural areas because of the difference in speed limit, and rate of accidents decreased with wider apron. The results showed that there was a clear relationship between the rate of accidents and the traffic volume—as traffic volume increases, accident rates increase. More studies on the influence of speed and geometric variables were undertaken by Brude and Larsson (2000) in a study in Sweden on accident data for 52 roundabouts from 1994 to 1997. They estimated a model that includes geometric variables and speed limit. The predicted regression model developed by the authors shows that accident frequency decreased by 14% at three-arm roundabouts compared to four-arm roundabouts; however, this frequency increases by 88% for the speed limit of 70 km/h compared to 50 km/h, and by 20% if the roundabouts are two-lanes compared to single-lane roundabouts. Moreover, Rodegerdts et al. (2010) concluded that a higher ICD decreases the deflection of vehicles that are circulating through the roundabout and this possibly leads to increasing speed within the circulatory lanes. They also stated that circulatory roadway width affects both safety and capacity. In addition, higher circulatory roadway width leads vehicles to overtake, and this increases the speed of vehicle. However, narrow circulatory lanes result in travel delay because vehicles cannot manoeuvre properly, and it limits the capacity of the roundabout.

Regarding the effect of signalisation on accidents, the Department for Transport (2009), in a signal controlled roundabout report, stated that the accident rate can be reduced by traffic signals; they also stated that signals can reduce the speed of circulating flow, which can improve safety. In a study on safety of signalised roundabouts undertaken by TLSM (2005) on 20 locations including 10 at-grade and 10 grade-separated roundabouts, it was found that when signals were installed at at-grade roundabouts, total collisions decreased by 28%, while in grade-separated roundabouts after implementation of signals the collisions decreased by 6%. They concluded that installation of signals at grade-separated roundabouts will not add any beneficial effects to roundabouts because accidents are decreased a by lower percentage compared to at-grade locations and this percentage was found to be insignificant statistically. However, in this study the effect of signalisation is investigated, which will be discussed in Chapter Five and Chapter Seven, and compared with the existing studies. One point should be taken into account—in this thesis signalisation is divided into signal, un-signal, and partial signal, and no previous studies have examined the effect of partially signalised roundabouts and their influence on the safety of roundabouts. In addition, previous studies have used traditional models while this study uses a random parameters model applied to the influence of these variables on accidents and HBIs.

The above studies illustrated the need for studying the influence of accidents at roundabouts and the parameters of influence. Previous studies suggested that variables that influence accidents are fixed (i.e. for instance, when a researcher states that accidents increase at two - lane roundabouts, this means that all two-lane roundabouts associated with a higher number of accidents and their effect is not varied across observations (i.e they have the same estimated coefficient parameter β). In reality, considering a random-parameters approach which accounts for unobserved heterogeneity and variables may not have a fixed effect across the roundabouts. For instance, some roundabouts that are two-lanes may have higher numbers of accidents whereas others with the same number of lanes may not have higher numbers of accidents, or may all have higher or lower number of accidents but the influence of two-lane varies across observations (i.e each observation has it is own coefficient β). Previous studies did not apply this approach to roundabouts, so one novel approach of this thesis is to apply this model to roundabouts. In addition, the effect of truck percentage in these studies is not taken into account for modelling accidents; however, this affect will be addressed at roundabouts. There are a limited number of studies on predicting truck accidents at roundabouts based on traffic and geometric variables. This shows that more investigation is needed to predict truck accidents with the same variables that are used for predicting total accidents. In these studies, the only model available for heavy vehicles is in the study of Daniels et al. (2010). Also, geometric variables in that study were found to have an insignificant effect on heavy vehicle accidents. According to the severity caused from truck accidents at roundabouts it is essential to promote and provide more details on truck accidents at roundabouts for better improvement and for future design, in addition to preventing the risk for future accidents arising from truck accidents. Table 2-5 summarises the models estimated in the reviewed literature.

Table 2-5 Previous Accident Models at Roundabouts

Country	Authors (year)	Number of Roundabouts	Model Developed
UK	Maycock and Hall (1984)	84	$A = kQ_t{}^{\alpha}$ or $A = kQ_e^{\alpha}Q_c^{\beta}$ (for entering-circulating)
			$A = kQ^{\alpha}$ (for approaching)
			$A = 0.052Q_e^{0.7}Q_c^{0.4}$ $e^{\Sigma -40\, entrycurviture + 0.14\, entry\ width - 0.007\, ev - 1\, RF + 0.2\, pm - .01\theta}$ (for entering-circulating)
			$A = 0.0057Q_e^{1.7}e^{\Sigma\, 20\, entry\ curviture - 0.1\, entry\ width}$ (for approaching)

Table 2-5 Continued

France	Guichet (1997)	12000	$A=0.24\times10^{-6}\ Q_t^{1.4}$
Australia	Arndt (1998)	100	$A = c_1 Q_e^{\alpha} Q_c^{\beta} S^z + c_2$
Italy	Montella (2007)	15	$A=5.73\times10^{-5}\ Q_{ee}^{\ 0.9470}$
South Korea	Kim et al. (2013)	9	*Accident number=exp(2.5764+0.1721 arm no.+0.2101 entry lane+0.1905 entry width+ 0.1845 circulatory lane no.+ 0.1598 flare width-0.0815 circulatory lane width)*
New Zealand	Harper and Dunn (2005)	95	$A=5.31\times10^{-4}\times Q_e^{0.47}\times Q_c^{0.29}\times e^{0.057 circulating\ width}$
New Zealand	Turner et al. (2006)	104	$A=6.12*10^{-8}\times Q_e^{0.47}\times Q_c^{0.26}\times free\ mean\ speed^{2.13}$ (for entering-circulating)
Sweden	Brude, and Larsson (2000)	52	$Total\ A = 6.11\times10^{-4}\times Q_e^{0.58}\times\emptyset_{MEL}$
			$A = 0.1353\ x\ 0.86^{3\text{-}arm}\ x\ 1.88^{speed70}\ x1.20^{2\text{-}lanes}$
Czech Republic	Šenk and Ambros (2011)	90	*Accident at urban two-lane* $(_{1\ year}) = 0.11 * AADT^{0.39} * e^{-0.17\ Apron\ width}$
			Accident at urban single-lane $(_{1\ year}) = 0.022 * AADT^{0.39} * e^{-0.17\ Apron\ width}$
			Accident at rural single-lane $(_{1\ year}) = 0.07 * AADT^{0.39} * e^{-0.17\ Apron\ width}$
Flanders, Belgium	Daniels et al. (2010)	90	$A = e^{-9.20}\times ADT^{0.89}\times BIC^{0.14}\times e^{0.40CYCLLANE}$
			$Heavy\ vehicle\ accident\ number = e^{-14.05}\times ADT^{1.23}$
United States	Rodegerdts et al. (2007)	-	$A = 0.000734\ Q_e^{0.7} Q_c^{0.13}\ e^{\sum 0.05 entry\ width - 0.027\ angle\ to\ next\ leg}$ (for entering-circulating)
			$A = 0.0000085\ Q_e^{0.28} Q_c^{0.25}\ e^{\sum 0.022\ inscribed\ circle\ diameter + 0.11\ circulatory\ roadway\ width}$ (for exiting-circulating)
			$A = 0.0057 Q_e^{0.46} e^{\sum 0.0301\ Approach\ half\ width}$ (for approaching)

Where:

A = the accident rates (accident/year)

Q_t = the total entry flow (sum of four arm flow)

Q_e = the entry traffic volume

Q_c = the circulating traffic volume which is equal to entry traffic volume

Q_{ee} = entry and exit flow

ADT is the average daily traffic

$k, \alpha, \beta, c_{1,} c_2$, $and\ z$ = model parameters;
ev = approach width correlation, RF = the Ratio Factor 1/(1 + exp (4R - 7)); R = ICD (m)/Central island diameter (m) , pm = the proportion of motorcycle; and θ = angle between arms in degree, (Maycock and Hall, 1984).

S = the 85th percentile speed in km/h

$\emptyset_{MEL}$ = the multiple entering lanes

3-arm = indicator variable (1 if three-arm; 0 if four), speed 70 is (1 if speed limit 70km/h; 0 if 50km/h), and 2-lanes is (1 if two-lane; 0 if one-lane)
BIC = the number of bicyclists and CYCLLANE = the cycle lane indicator (1 if yes; 0 if no)

2.3.7 Summary

This section illustrated types of roundabouts, geometric characteristics of the roundabouts, road marking, and shape of central island, and general accident trends at roundabouts. Then in detail the general traffic and geometric characteristics influencing accidents at roundabouts are presented.

A significant decrease was observed in the number of accidents when intersections were converted into roundabouts, based on several studies carried out by Jacquaemart (1998), Elvik (2003), Retting et al. (2001), Persaud et al. (2001), Rodegerdts et al. (2007), Garder (1998), and Isebrands (2009). However, this highlights that the number of casualties decreased when intersections were changed to roundabouts, but studies revealed that still, accidents occurred at roundabouts. For this reason, a number of studies have been carried out on trends at roundabouts and on major factors influencing accidents at roundabouts. A summary of the general accident trend shown by a number of studies is in Table 2-6.

Table 2-6 Summary of General Roundabout Accident Trend

Study and country	Years studied	HGVs percentage	% of fatalities and serious injury	Weekday and weekend rate	Month of the year	Time of the day
Maycock and Hall (1984), UK	1974-1979	6 to 8%	16% all vehicles	Friday is the highest, and Sunday is the lowest	October is the highest and April is the lowest	Evening peak higher than morning peak
Harper and Dunn (2003), New Zealand	1998-2002	6%	8% at two-lane and 15% at single-lane	Not available (N/A)	N/A	25% occurred at night
Kennedy (2007), UK	1999-2003	9.3%	9.3% at three-arm and 7.1% at four- and five-arm, respectively.	Friday records the highest rate; Sunday records the lowest rate	November is the highest, April is the lowest	Evening peak higher than morning and mid-day peak

In a study by Maycock and Hall (1984), the accident rate decreased over the period of 1974-1979 from 0.87 to 0.82, and in Kennedy (2007), the accident rate decreased by 6.84% between 199 and 2003. This shows that the trend of decreasing accidents is in line with general accident trend reductions at road segments. The rate of HGVs compared with other vehicle types is low, but the percentage of fatalities and serious injuries included in HGVs is higher relative to cars and taxis, as indicated by Kennedy (2007), and HGVs are involved in 8% of fatalities and serious injuries, while cars and taxis accidents are involved in 6% of fatalities and serious injuries. This indicates that trucks are dangerous on the roads, even when the percentage of goods vehicles is not high, compared with other vehicle types.

The only predicted model available for trucks at roundabouts was undertaken by Daniels et al. (2010) who found that ADT is the only variable that influences increasing truck accidents.

A summary of researchers' findings about the parameters that are considered in this thesis is shown in Table 2-7.

Table 2-7 Summaries of Findings in the Literature on Parameters that are Included in this Study

Researcher	Traffic volume	Entry width	ICD	Circulatory roadway width	Number of circulatory lanes	Number of lanes	Number of Arms	Signalisation
Kennedy (2007)							Higher number of arms higher accidents	
Retting (2006)		Higher entry width Less safe	Higher ICD less safe	Higher Circulatory roadway width Less safe				
AASHTO (2014)	Are major input in to the safety performance							
Daniels et al. (2010)	ADT increases total and truck accidents		Have no effect			Have no effect		
Maycock and Hall (1984)	Accidents increased with increasing number of traffic volume	Higher entry width increase entering/circulating accidents Lower entry width lower approach accidents	Higher the ratio of ICD to central island diameter higher accident rates					
Guichet (1997)	Higher traffic volume higher accident rate							

Table 2-7 Continued

Harper and Dunn (2005)	Higher traffic volume higher accident rates			Higher circulatory roadway width higher accident rated					
Montella (2007)	Higher traffic volume higher accident rates								
Arndt (1998)		Safety increased if entry width decreased	Smaller ICD provide safety for roundabouts	Safety increased if circulatory roadway width decreased					
US DOT (2007)		Higher entry width less safe				Higher entry lanes higher accidents			
Rodegerdts et al. (2010) and (2007)		Higher entry width higher entering/circulating accidents	Higher ICD roundabout will be less safe	Circulatory roadway width effects both safety and capacity, higher width higher speed and less safe		Multilane approaches and roundabouts are unsafe relative to single lane approaches and roundabouts			
Kim et al. (2013)		Higher entry width higher accidents		Accident number decreased with increasing circulatory width	Accident increases with increasing number of circulating lanes	Higher entry lanes higher accidents	Higher number of arms higher accidents		

Table 2-7 Continued

Turner et al. (2006)	Higher traffic volume higher number of accidents					Multiple entry lanes have higher number of accidents relative to single-lane roundabouts		
Šenk and Ambros (2011)	As traffic volume increases accident increases					Two-lane had higher accidents than single-lane		
Brude and Larsson (2000)						Two-lanes have higher accident rates than single-lane	Three-arms have lower number of accidents relative to four arms	
Shadpour (2012)	Higher AADT, higher accidents					Higher number of lanes higher accidents	Higher number of arms higher accidents	
Persaud et al. (2001)	AADT increase frequency of accidents at major and minor roads							
Department of Transport (2009)								Accidents reduced by installing signals
TLSM (2005)								At-grade and grade-separated roundabouts accidents decreased when they are signalised

The studies presented in Table 2-7 indicate the major geometric and traffic variables influencing accidents at roundabouts using Poisson and NB distribution, except Arndt (1998) who used linear regression models. They illustrated that in all models traffic volume is the major factor influencing accident numbers or rates. Each study has included a number of geometric variables, but the majority of them state that ICD, number of legs, number of lanes, entry width and speed of vehicles have a significant influence on accident rate or numbers. In this study the effects of these variables except speed will be included in order to explore their influence on accidents, truck accidents, and HBI as a whole, within circulatory lanes, and at approaches to the roundabouts. However, in this study, for the first time, type of grade, more details in signalisation, and percentage of truck traffic, were added to the models. The previous models used traditional NB distribution, so in this thesis the influences of the geometric and traffic variables were undertaken using a random parameters model. According to previous studies, no studies have been undertaken using random parameters models to investigate accidents at roundabouts.

2.4 Overall Chapter Summary

In summary, this chapter gives a review of the studies undertaken previously by the researchers in the area of traffic accidents. It can be concluded that the number of accidents, deaths, and seriously injured casualties have decreased over the last decades at both road segments and roundabouts, which supports the thesis problem statement, that the number of blackspots have decreased, and so, other methods are required to identify and report the unsafe conditions and acts.

Accident models have been widely studied using different prediction models, but, because accidents are count data, non-negative, and discrete, researchers have usually employed Poisson regression models to predict count data. However, previous studies on predicting the accidents at roundabouts used the fixed effect of NB and Poisson regression models. Researchers have introduced random parameter models to count data and applied this model to the road segments, (for instance: Anastasopoulos & Mannering, 2009; El-Basyouny & Sayed, 2009; Garnowski & Manner, 2011; Ukkusuri et al, 2011; Venkataraman et.al ,2014), and stated that if parameters are considered fixed across the observations, the model may be biased, and possible wrong conclusions may be drawn. No studies showed the same application on the roundabouts. For this reason, this study (thesis), applies this approach for the first time to predict HBIs, total accidents, and truck accidents at roundabouts, based on geometric and traffic variables.

Linear regression or traditional NB models were used to identify accidents at roundabouts (see Table 2-6). Some variables that were previously studied were included in this study, for instance, entry width, ICD, circulatory roadway width and lane, and approach lane; other factors were not included because of the unavailability of the data.

Studies showed that truck accidents are dangerous because of their size, carrying load and configuration, and their manoeuvre as stated by the DFT (2014), Trucks V (2013), US Department of Transportation (2014), Grygier et al. (2007), and Carstensen et al (2001), the majority of fatalities would be the drivers of passenger cars when the accidents are recorded between the trucks and other type of vehicles. In this thesis, Chapter Four illustrates the trends and casualties from truck accidents at roundabouts and compares the results to total accidents and to the previous studies.

With regards to near-miss accidents, and HBIs, there are a number of studies which have been undertaken about the influence of driver behaviour on the occurrence of harsh braking or near-miss accidents. According to the previous studies (Bayan et al., 2009; Dingus et al., 2005; Fitch et al., 2009; Greibe, 2007; Grygier et al., 2007; Kessler et al., 2012; OGP, 2014; Fazeen et al., 2012; Olson et al., 2009; Blanco et al.,2011; Haque et al., 2016; Harbluk et al., 2007; Inman et al., 2006; Klauer et al., 2006; Klauer et al., 2009; Simons-Morton et al., 2009; Geotab Inc., 2015) the harsh braking longitudinal deceleration is defined as being from >0.2 g (1.96 m/s^2) to a maximum of 0.86 g (8.44 m/s^2). These studies show the influence of driver behaviour on braking, and near-miss accidents, while, in this thesis, different factors from the ones mentioned previously were included, in order to identify the relationship between accidents and HBIs. It should be taken into account that these studies explored near-miss accidents, including all types of manoeuvres, and not only harsh braking.

Chapter 3 Data Description and Methodology

3.1 Introduction

This chapter describes the data sources, data description, procedure, and the methods that have been carried out for investigating truck sensor position data to analyse HBIs, as well as the model development methodology for total accidents, truck accidents, and HBIs. In general, the dependent variable, also called the response variable, and independent or exposure variables were used in model development: the dependent variable represents the output or effect; in this study total accident, truck accident, and HBI numbers were the dependent variables. The independent variables (in this study traffic and geometric characteristics) represent the inputs or influences on the dependent variable, and are tested to see if they have an effect on it, which provides information about the dependent variable. The dependent variable is correlated to independent variable(s) by regression analysis and the outcome of the relation is called a prediction model or an estimated model.

The main aim of this study is to investigate the feasibility of using truck harsh braking data to contribute to accident analysis, and as discussed, the main objectives of this study are to:

- Characterise the incidence of harsh braking at a number of roundabouts.
- Compare these characteristics to factors known to influence accident rates.
- Investigate the relationship between accidents and HBIs.
- Explore if analysis of HBIs can contribute additional information to accident data for road safety studies.
- Make recommendations for taking this idea forward.

In order to achieve these objectives a methodology is undertaken (as shown in Figure 3-1), and will be discussed in detail in the subsequent sections.

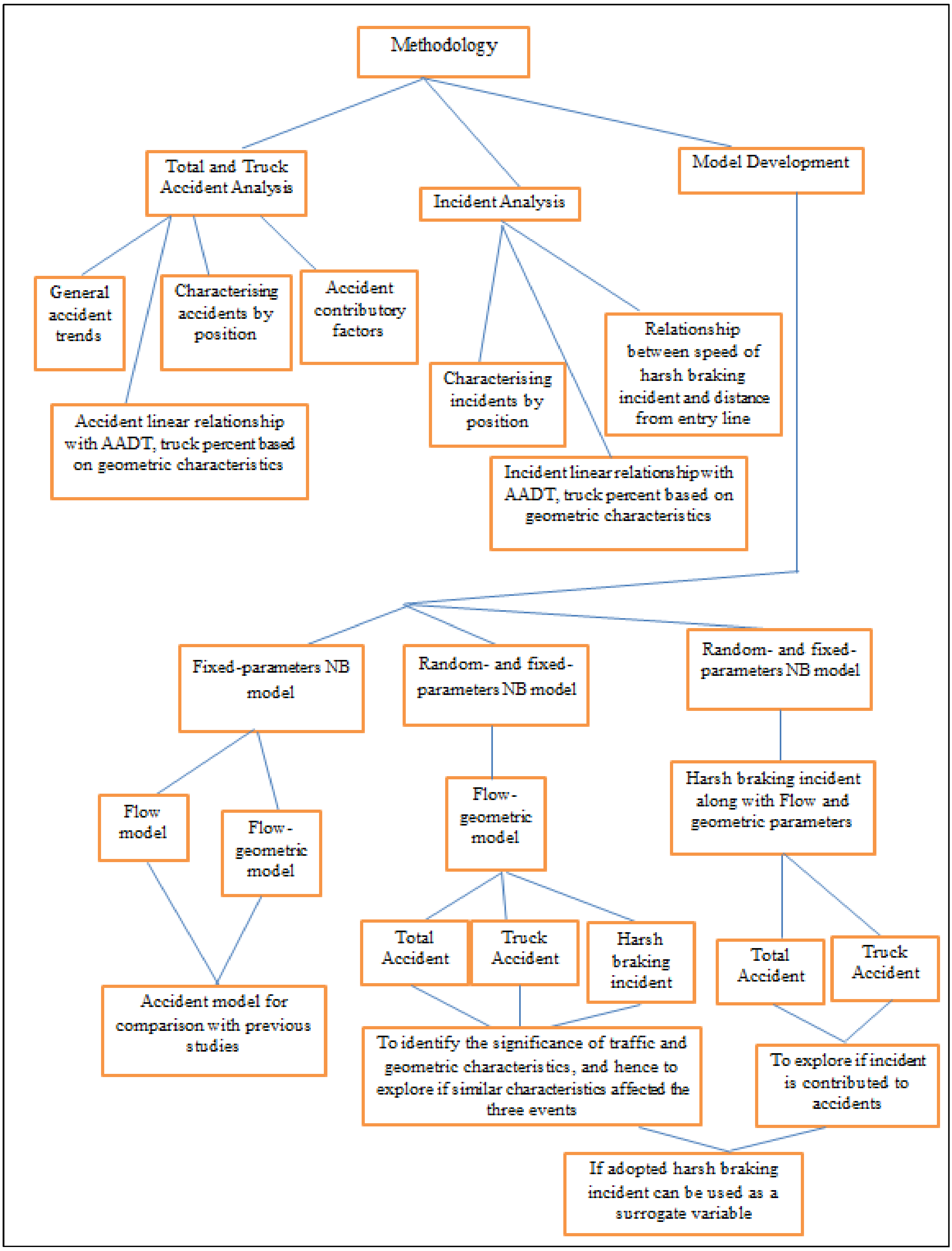


Figure 3-1 Methodology Framework

3.2 Data Sources

3.2.1 Truck Incident Position Data

Most modern truck fleets record position as part of fleet management. This research used position data collected by the truck telematics company Microlise Ltd. for 8,000 trucks in the UK from 2008 to 2013. For the two years 2011 and 2012, 195,297 incidents of harsh braking were recorded throughout all UK roads and intersections. A harsh braking event is a telematics event measured from the vehicle CAN and derived from the axle speed value (also derived from GPS for non-CAN vehicles). Telematics units are fitted in the vehicle and the location varies based on vehicle model and marque. It is commonly fitted under the dashboard.

3.2.1.1 How the Microlise Telematics Unit Works

The control functions of the vehicle recorded by the telematics unit is packaged up and immediately sent to the company server through the mobile phone network and stored in a safe place (see Figure 3-2). The telematics unit records information 30 seconds before and after the incident occurs, including speed, direction, accelerator position, braking, ABS status, gears, cruise control, and clutch data (Microlise, 2016).

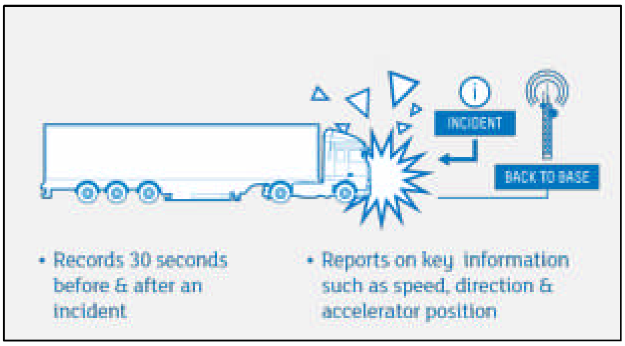


Figure 3-2 Recording Incidents and Sending Back to Base (Microlise, 2016)

3.2.1.2 Definition of Harsh Braking Incident

Microlise Ltd. defines harsh braking as a sudden reduction of vehicle (i.e. truck) speed deemed to be excessive, and likely caused by bad forward-planning for the situation ahead (e.g. roundabout, traffic lights changing, junctions etc.). Table 3-1 illustrates the percentage of vehicle types in the system currently. The percentage of vehicles types and weights in the Microlise system is not available for 2011 and 2012, but according to their records all vehicles are $\geq$ 3.5 tonnes (T).

Table 3-1 Percentage of Vehicle Types and Weights in the System of Microlise Ltd.

Vehicle Gross Weight	Percentage of Trucks
7.5 T	1
16 T	1
18 T	50
20 T	43
23.4 T	5

For 2011/2012 data, truck position was recorded using standard GPS equipment, for the purposes of delivery logistics etc. Any point which records a deceleration of speed of a specified magnitude over a specified duration is flagged and its location is recorded. The default value varies between -8 and -16 km/h /s, based on customer requirements (i.e. type of operation, type/size of the vehicle etc.). As such, this threshold could be high for a van and low for a heavy (20 T) truck. As a deceleration rate, this value is between 2.22 (heavy truck) and 4.44 m/s^2 (van or light truck); this value is the minimum value that triggers the recording of a HBI. Therefore, if the speed of the vehicle is reduced by 8 km/h over one second, the unit records a harsh braking event. Due to the configuration of the unit, in the data used in this thesis a harsh braking event is recorded only once for the same vehicle over a single occasion. For instance, in case of reducing speed from 80 km/h to 0 km/h in five seconds with continuous deceleration, only one event (rather than five events) will be logged. In this case, the reported GPS speed for the harsh braking is the last speed reading (at the point that the harsh braking event is detected (i.e. the end speed). Table 3-2 illustrates a sample of HBIs in the east direction of J16 on the M4. These data illustrate the HBI date and time with location coordinates in addition to the speed of the truck when the harsh braking was recorded. It is clear that each point is recorded at a different date and time.

Table 3-2 Sample of HBIs (East of J16 on the M4)

Event date	Event time hr: min: sec	Latitude	Longitude	Speed (km/h)
07/03/2011	06:15:00	51.54626	-1.85485	27
16/03/2011	02:35:00	51.54609	-1.85434	23
16/03/2011	07:42:00	51.54639	-1.85539	42
25/03/2011	09:47:00	51.54612	-1.8542	19
02/04/2011	08:25:00	51.54603	-1.85421	11
09/04/2011	09:37:00	51.54613	-1.85417	13
13/04/2011	08:42:00	51.54626	-1.85507	37
21/04/2011	20:07:00	51.54618	-1.85413	13
25/04/2011	03:44:00	51.54617	-1.85448	26
03/05/2011	07:41:00	51.54611	-1.85417	15
09/05/2011	11:43:00	51.54604	-1.85411	8
11/05/2011	03:19:00	51.5462	-1.85449	26
12/05/2011	19:50:00	51.54611	-1.85414	15
16/05/2011	03:15:00	51.54619	-1.85449	39
19/05/2011	03:01:00	51.54626	-1.85476	47
20/05/2011	18:45:00	51.54618	-1.85443	26
21/05/2011	11:40:00	51.54616	-1.85423	14
29/05/2011	06:19:00	51.54608	-1.85436	23
04/06/2011	08:58:00	51.5462	-1.85447	34
08/06/2011	00:04:00	51.54611	-1.85432	33
12/06/2011	13:39:00	51.54614	-1.85425	27
28/06/2011	13:45:00	51.54609	-1.85408	5
03/07/2011	13:14:00	51.54614	-1.85424	21
06/07/2011	12:23:00	51.5462	-1.85438	22
14/07/2011	03:44:00	51.54622	-1.85482	30
15/03/201	04:07:00	51.54611	-1.85422	14

3.2.1.3 Validation of the Harsh Braking Incident

As stated previously, the harsh braking points from Microlise trucks were recorded at a minimum deceleration of between 2.22 and 4.44 m/s^2 depending on type of goods vehicle. Threshold accelerators were used to measure and compare these figures to those obtained in test truck trials at the Transport Research Laboratory (TRL), undertaken with a 3.5 T Microlise truck, in order to check at what deceleration trucks recorded incidents and to compare with the original harsh braking thresholds used in this study. The truck was fitted with smartphones, which were used as data-collection tools by Byrne et al. (2013) for detecting deterioration in pavements using smartphone accelerometers; they described the optimum positioning and orientation of smartphones for this purpose. As shown in Figure 3-3, the smartphone was fitted with its screen facing up and kept in portrait position, placed in the centre console of the trucks and rigid to the edges of the console in order increase the sensitivity of the smartphone's accelerometers to the truck movements (Byrne et al., 2013). For each trial, the start time, end time and speed were recorded along with acceleration from the smartphones and truck position from the Microlise equipment. The test started at 09:57:55 and ended at 11:10:48, the model of the phone was a Desire HD Android version 2.2, and the accelerometer threshold was 0.05 m/s^2; this threshold was set in order to avoid recording negligible values of accelerations that would result in a large and noisy file. The outputs of the installed phone are X, Y and Z accelerations; X, Y and Z orientations; latitude and longitude; and GPS velocity and bearing.

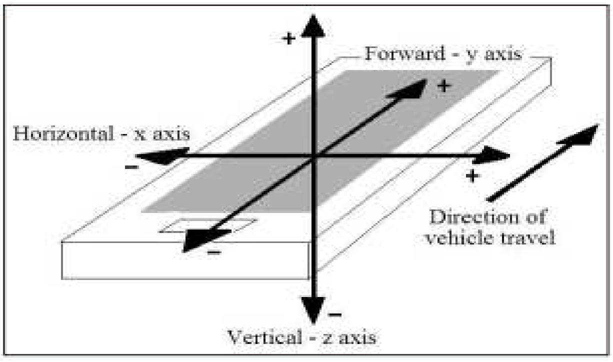


Figure 3-3 Smartphone Position and Accelerometer Orientation (Byrne et al., 2013)

Gentle and quick straight-moving manoeuvres with gentle and harsh braking (at speeds of 40, 50, and 56 mph) were conducted, and recorded harsh braking events were identified. Figure 3-4 shows harsh braking events for a straight quick acceleration, a lane change, and a harsh braking manoeuvre. The green point is the start point of movement for the truck, which then increases in speed based on the type of manoeuvre chosen, after which it attains the desired speed, at which point it changes lane, lowers speed and brakes harshly (the yellow button), turns and starts increasing speed then stops (red button). Each manoeuvre was undertaken for a duration of 60 seconds, and the numbers of accelerations and decelerations were recorded. Figure 3-5 illustrates the longitudinal acceleration for the first trial straight, quick acceleration, lane change, and harsh braking at speed 40 mph.

Table 3-3 illustrates the maximum longitudinal deceleration for each manoeuvre that recorded HBI. Three trials of “straight quick acceleration, lane change, and harsh braking” with a speed of 40 mph (64 km/h) were recorded. For the first trial, maximum longitudinal deceleration (mainly responsible for HBIs, as discussed in 2.2.3) was 8.7 m/s^2; for the second trial it was 8.5 m/s^2; and for the third, 8.6 m/s^2. On average the maximum longitudinal deceleration for this manoeuvre with recorded HBIs was 8.6 m/s^2.

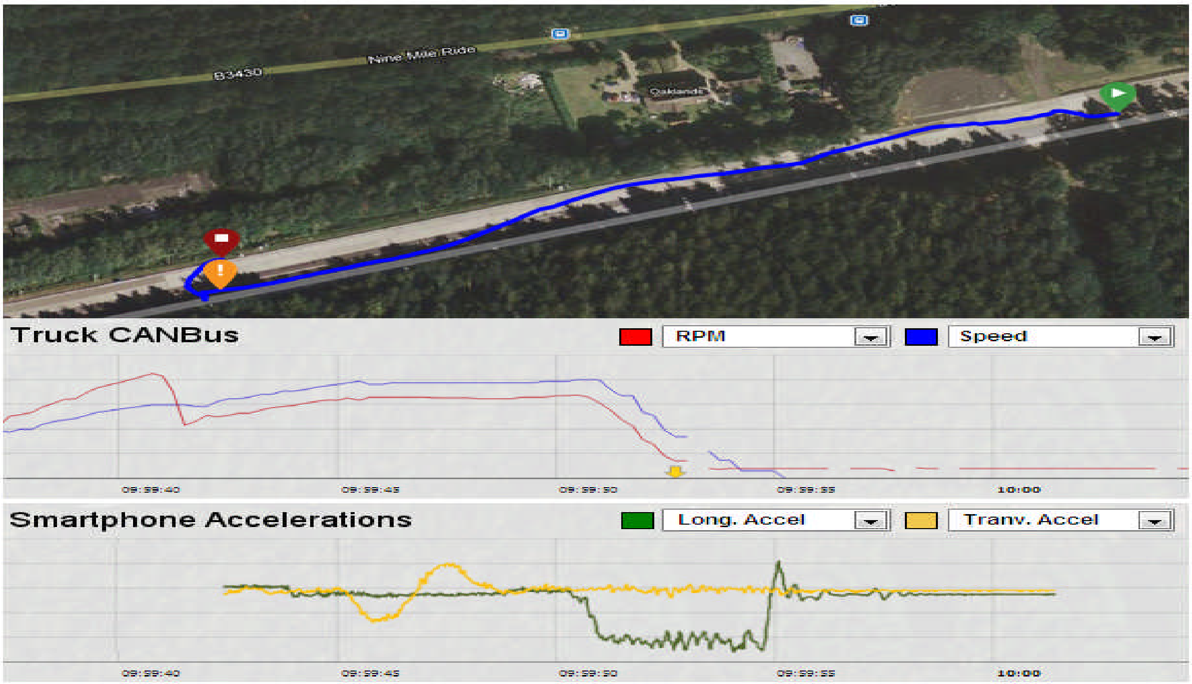


Figure 3-4 Incident Analysis Details for Straight Acceleration, Lane Change, and Harsh Braking Manoeuvres

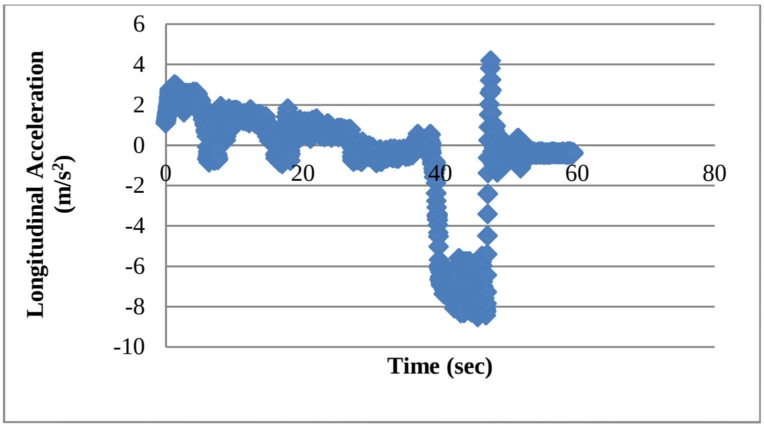


Figure 3-5 Longitudinal Acceleration for Straight, Quick Acceleration, Lane Change, and Harsh Braking, Speed 40 mph (First Trial)

Table 3-3 Maximum, Average, and Longitudinal Deceleration Details for Recorded Incidents

Manoeuvre Type	Max longitudinal deceleration (m/s^2)
Straight quick(ish) acceleration, lane change, and harsh braking (speed 40mph)	8.60
Straight quick(ish) acceleration, lane change, and harsh braking (speed 50mph)	8.55
Straight quick(ish) acceleration, lane change, and harsh braking (speed 56mph)	8.51

With speeds increased to 50 mph (80 km/h), Table 3-3 indicates that harsh braking at this speed recorded an incident and the max longitudinal deceleration for this manoeuvre was 8.55 m/s^2. When the speed was increased to 56 mph (90 km/h), one trial was undertaken and lasted 60 seconds, and different accelerations and decelerations were recorded. Table 3-3 indicates that HBIs were recorded, and the maximum longitudinal deceleration for this event was of 8.51 m/s^2. Note that as speed increases the longitudinal deceleration rate decreases by a small amount. Benmimoun et al. (2011) using CAN data trucks recorded a deceleration of 6 m/s^2 at speed of less than 50 km/h, and when speed was between 50 to 150 km/h, the deceleration decreased to 4 m/s^2.

As stated previously, Microlise trucks record a HBI based on type/size of the vehicle when there is a reduction in speed of ≥ 8 to 16 km/h during one second, which converts to 2.22 to 4.44 m/s^2, and based on smartphone accelerometer, the test truck (3.5 T in size) recorded incidents at maximum deceleration of 8.51 to 8.6 m/s^2 based on different speeds. This indicates that the threshold set by Microlise Ltd. is valid, as it is less than the maximum deceleration identified from the trials identified by smartphone accelerations. For heavy vehicles, DDWS FOT uses a trigger of ≥ -3.34 m/s^2, while NTD uses a trigger of ≥ -1.96 m/s^2 to be considered as harsh braking. Similarly Blanco et al. (2011) use a deceleration of >1.96 m/s^2as HBI trigger for trucks. And, Grygier et al. (2007) recorded harsh braking for a maximum deceleration of 7.4 m/s^2 for trucks. Regarding HBIs at roundabouts, Haque et al. (2016) have found passenger cars records HBIs at deceleration of 4.43 m/s^2, 4.96 m/s^2, 5.15 m/s^2 in case of no phone, hand-free, and hand-held conversation, respectively.

For passenger cars at intersection near-miss accidents and incidents were recorded at an average deceleration rate of 0.51 g (5 m/s^2) and 0.66 g (6.47 m/s^2), respectively, (Lee et al., 2007). Harsh braking recorded at maximum deceleration of 0.67 g (6.57 m/s^2) was noted by Inman et al. (2006), and braking was considered harsh at longitudinal deceleration of >0.25 g (2.45 m/s^2) by Harbluk et al. (2007).

According to the results of previous studies, as shown in Table 2-3 for other types of vehicles (Dingus et al., 2005; Klauer et al., 2006; Greibe, 2007; Kessler et al., 2012; Bayan et al., 2009; Fitch et al., 2009; Simons-Morton et al., 2009; Geotab Inc., 2015) the harsh braking longitudinal deceleration varies from a min of 0.25 g (2.45 m/s^2) to a maximum of 0.81 g (7.9 m/s^2), with an average of >0.5 g (4.9 m/s^2), based on the stated maximum deceleration, minimum deceleration or average. In addition, OGP (2014) reported that their vehicles detect HBIs at or above a speed reduction of 9.65 km/h/s (2.68 m/s^2), which is close to the minimum declaration value monitored by Microlise trucks. Fazeen et al. (2012), in a similar study to the study that undertaken in TRL (using cars instead of trucks), illustrated that longitudinal deceleration of greater than 3 m/s^2 is considered unsafe. Moreover, the threshold set by Microlise Ltd. for HBIs is greater than that of NTD and Blanco et al. (2011), and it is within the range and in line with the previous studies' results, and from this point these data can be used for the purpose of achieving the aims and objectives of the study.

3.2.2 Accident Data

The accident data from STATS19 includes information about collision circumstances (accident reference, year, accident severity, time and date, weekday, weather and lighting condition, road type and road surface condition, vehicle and casualty numbers, easting/northing coordinates, etc.), vehicle details (accident reference, type of vehicle, etc.) and reported contributory factors related to the accidents. Accident data for the selected roundabouts were collected from the STATS19 database for the 11 years from 2002 to 2012 (the use of data over 11 years was chosen as a compromise, to generate a significant number of accidents while not being so long as to be unrepresentative of current circumstances), and as stated in Chapter One Figure 1-1, the number of accidents is much smaller than the number of HBIs. Data outside this period is not included in the analysis because in the last decade a lot of changes have been made to the roads and intersections.

3.2.3 Traffic Data

AADT and percentage trucks data were acquired from Department of Transport, Traffic Counts (DfT, 2016) for the years 2011 and 2012.

3.2.4 Geometric Data

Roundabout entry width, circulatory roadway width and ICD, signalisation, number of lanes, and type of grade were calculated for the selected roundabouts from aerial photographs on an online mapping site; in addition, road markings, truck aprons, and shape of central island were investigated using aerial photographs. Figure 3-6 defines the roundabouts' geometric information.

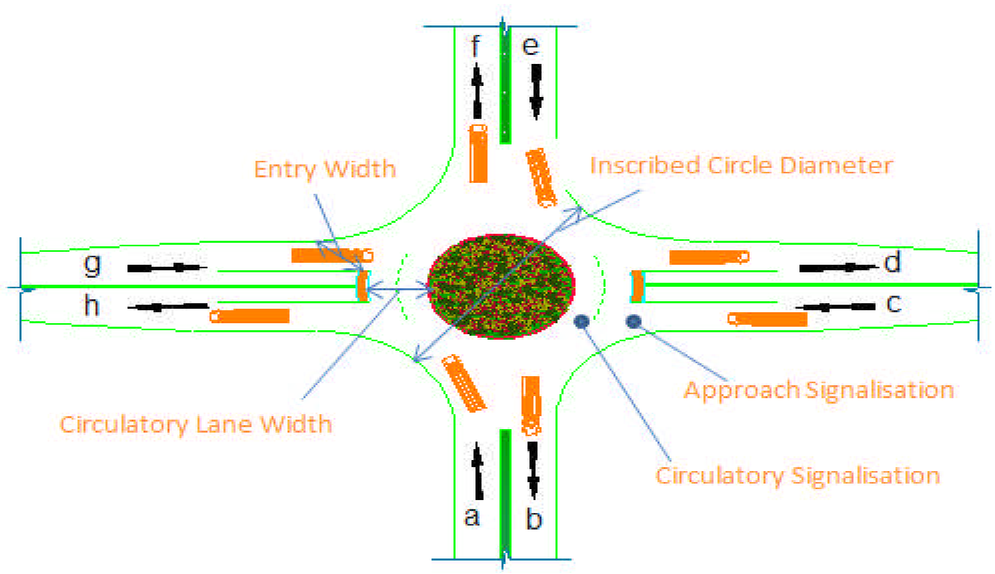


Figure 3-6 Geometric Elements of Studied Roundabouts

3.3 Data Description, Filtration, and Procedure

The principal objective of this thesis is to identify the major characteristics of HBIs, total accidents, and truck accidents with respect to a number of geometric characteristics and with respect to AADT and the percentage of truck traffic. Hence, comparing the characteristics that influence HBIs to those known to influence total and truck accident, this will allow the explanation of if it is feasible to use truck HBIs to identify locations with high accident risk based on HBIs at a number of roundabouts. Data was identified in different sources as described in the previous section. The following gives detailed descriptions and illustrates the processing procedures of the data included in this study in order to achieve its aims and objectives.

3.3.1 Description of the Selected Locations

In order to identify the locations that triggered HBIs, the Earth Point program, Excel to KML, was used, which displays Excel files on Google Earth and can be found at (Earth point, 2016). The position data (latitude and longitude coordinates) are imported to Google Earth. An inspection of the locations of these HBIs revealed that the majority occurred on the approaches to roundabouts, Figure 3-7 shows roundabout locations, and Figure 3-8 shows a sample of the selected locations with HBIs clustering around the approaches and circulatory lanes.

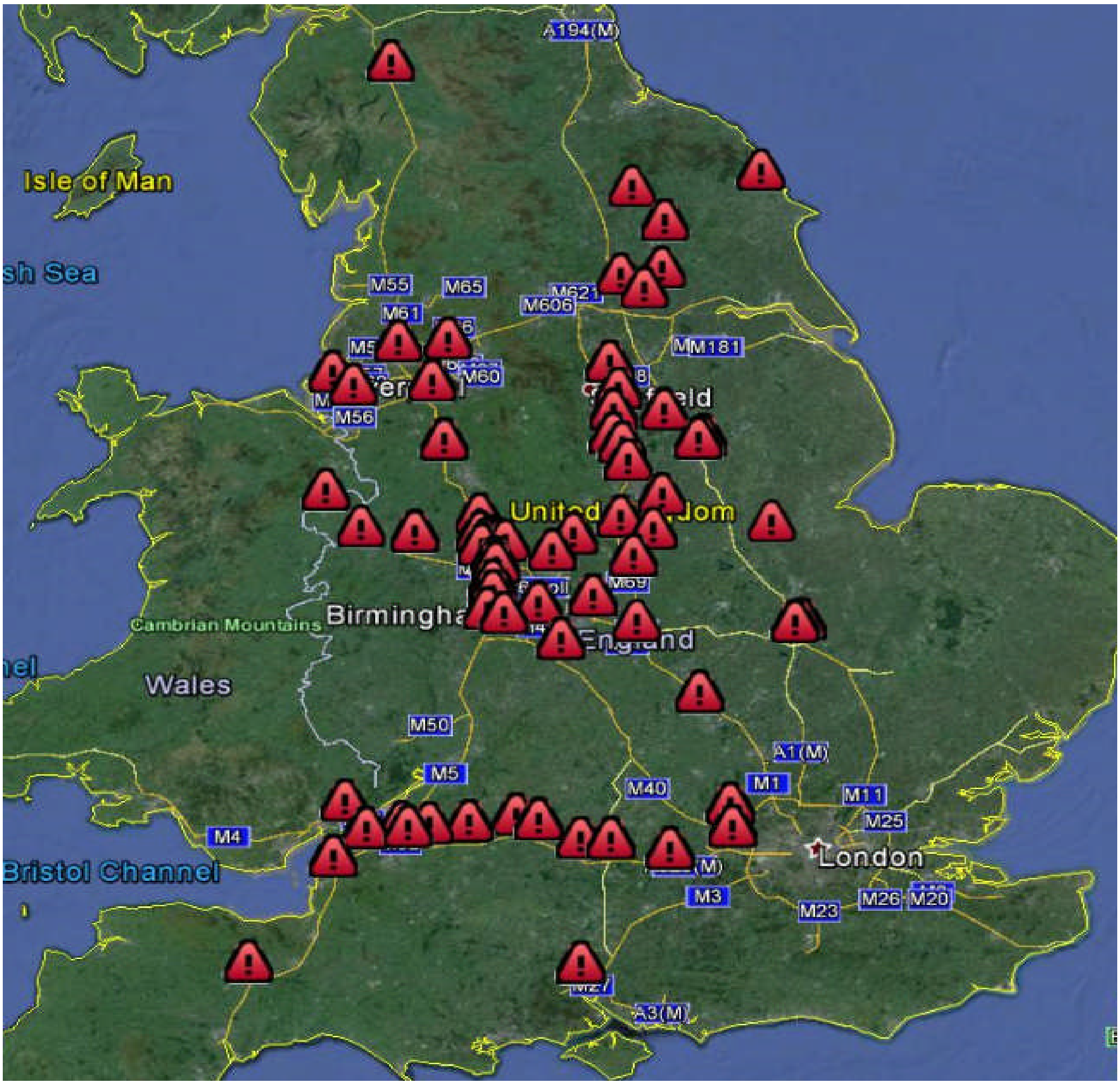


Figure 3-7 Selected Roundabout Locations

Figure 3-8 Samples of the Selected Roundabout Locations with HBIs

After the data were uploaded to Google Earth, because the majority of HBIs were clustered around roundabouts, 70 roundabouts covering 294 approaches with low and high occurrences of HBIs were selected randomly. Note that of the 294 approaches of the selected roundabouts, for modelling purposes 284 were analysed, as the other ten approaches were located on roads that are not classified and traffic data for these kinds of road are not available. The selected roundabouts comprise nine roundabouts on the M1, ten roundabouts on the M6, six roundabouts on the M5 and nine roundabouts on the M4, with the others located on different motorways and A-class roads. Table 3-4 describes the characteristics of the 70 roundabouts, and Table 3-5 describes the characteristics of the roundabout approaches. The roundabouts have different numbers of arms, but the majority of them have four. In addition, the majority of the selected locations are grade separated.

Table 3-4 Whole Roundabout Characteristics

No.	3-arm	4-arm	5-arm	6-arm	Traffic signals	No traffic signals	Partially signalised	2-lane	3-lane	At-grade	Grade-separated
70	12	39	12	7	20	28	22	39	31	19	51

Table 3-5 Roundabout Approach Characteristics

No.	Traffic signals	No traffic signals	2-lane	3-lane	At-grade	Grade-separated	A road	M road	B road
284	142	142	172	112	73	211	174	94	16

The following is the description of each category used in this study for the roundabout as a whole, within the circulatory lanes, and at approaches:

- A roundabout is considered signalised when it is signalised at approaches and within the circulatory.

- A roundabout is considered un-signalised when it is un-signalised at approaches and within the circulatory.

- A roundabout is considered partially signalised when one or more of the approaches and circulatory lanes are signalised, but not all.

- Entry width for a roundabout taken as a whole is the average approach entry width, while at approaches it is the entry width at each individual approach.

- Traffic volume (AADT and percentage of truck traffic) for each roundabout and for the circulatory is the sum of the traffic volume at the roundabout's approaches.

- Traffic volume (AADT and percentage of truck traffic) at approaches is the volume at each individual approach.

- When the roundabout has two circulatory lanes, and all approaches or the majority of approaches are two-lanes, this roundabout is as a whole considered to be a two-lane roundabout, and similarly for three-lanes.

- Individual approaches either signalised or un-signalised, and either they are two-lanes or three-lanes.

3.3.2 Harsh Braking Incidents

The truck HBI spreadsheet supplied by Microlise Ltd includes speed, date, time, longitude, and latitude (see Table 3-2). One objective of this study is to characterise HBIs to a number of factors, for this reason this section illustrates the procedures that are undertaken to filter, allocate, and count HBIs at the selected roundabouts, which will help understand the general characteristics of HBIs illustrated in Chapter Six, in addition to obtaining the number of HBIs for modelling purposes that is illustrated in Chapter Seven and Chapter Ten. Following is the procedure:

- As discussed earlier, the coordinates of HBIs (latitude and longitude) were uploaded to Google Earth using Excel to KML program.

- After the data was uploaded, locations were selected; the numbers of HBIs in each selected roundabout approach and within the circulatory lanes for the purpose of analysis were counted manually from Google Earth.

- To understand the general characteristics of HBIs, the distance between the point of each HBI and the entry line is identified for each of the selected 284 roundabout approaches; in addition to explore at what speed these braking incidents happened, the relationship between the distance that trucks recorded harsh braking away from the entry line and speed was examined. This process was undertaken to explore general trends of harsh braking, that is, if the distance changes based on the speed data available. From the Microlise data sheet there is no column describing at what distance the HBI was recorded; the only information available is latitude and longitude, and for all the HBIs the distance between the two points was calculated by the following formula (Lentz, 2008):

$$D = R_E \times \cos^{-1}((\cos(R(90 - Lat_1)) \times (\cos R(90 - Lat_2)) + (\sin(R(90 - Lat_1)) \times (\sin(R(90 - Lat_2)) \times (\cos R(Long_1 - Long_2)))) \qquad (3\text{-}1)$$

where:

R_E= Earth Radius which is 6378.135 km

D= Distance is in km

R= Radiance

Lat_1 and Lat_2 are the latitude of the first point and second point in decimal degrees, respectively.

$Long_1$ and $Long_2$ are the longitude of the first point and second point in decimal degrees, respectively.

Note that the latitude and longitude of the HBIs in this study was in decimal degrees (DD), in case of Degrees° Minutes´ Second″ (DMS) the Lat_1, Lat_2, $Long_1$ and $Long_2$ shown in Eq. (3-1) should be multiplied by 24 to convert them to DD.

- Since Microlise's Excel data is for all UK roads and intersections, in order to filter the selected locations, the latitude and longitude from the centre of the roundabout was used as the main distance, and the distance between latitude/longitude from the centre of the roundabouts and all other points (over 195,297 HBIs) on the UK roads and intersections were calculated. Then the IF logical statement test in Excel was used (IF (logical_test, [value_if_true], [value_if_false])) in order to filter the selected roundabouts and copied to a different Excel sheet. The majority of HBIs occurred within 350m of the roundabouts (see Figure 3-9 for a sample of roundabout), so this distance was used as the distance from the roundabout centres to the final point of the HBIs within the roundabout. The same processes were carried out for the other 69 roundabouts using the latitude and longitude of the centre of the roundabouts and the IF logical statement.

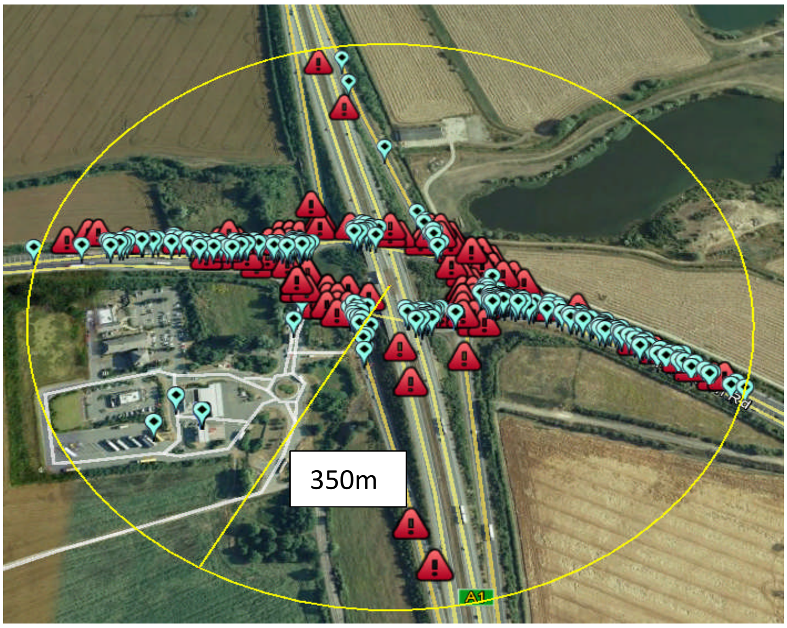


Figure 3-9 HBI and Accidents Clustered Around A1/A14 Junction

- After each of the selected locations was filtered from the complete data of the UK roads and intersections, a similar process was carried out for each of the selected locations in order to allocate the HBIs to individual arms. In this case, the latitude and longitude of the entry line of each individual approach was used as a base and the distance was identified, then IF statements were used to filter each approach, with this process repeated for the remaining 293 approaches. Note that after each approach was filtered, the data were uploaded to Google Earth to check if they were located at approaches and not located nearby or in fields (because sometimes there are parking areas or buildings located close to the selected roundabouts as can be seen in Figure 3-9).

- Signalisation was investigated using the online mapping site Google Earth, the approaches that are signalised and located in at-grade roundabouts were all copied and pasted to a different Excel sheet, the same process was repeated for un-signalised approaches that are on at-grade roundabouts, and for signalised and un-signalised approaches that are located on grade-separated roundabouts. Note that the roundabouts were analysed according to grade separation because grade separation was used as an indicator for the later modelling. Then the relationship between driveway distance and speed was examined, in order to explore at what speed and distance away from the entry line the trucks recording HBIs.

- From the HBI spreadsheet (see Table 3-2), there is a column that indicates at what time the HBI occurred, which was used to specify peak and off-peak periods (note that based on DFT,

2015) the morning peak was defined as 7:00am to 9:00am; evening peak 4:00pm and to 6:00pm). This process was undertaken in order to see how congestion influences HBIs, and hence to compare the results with previous studies.

- Note that numbers of HBIs were counted manually from Google Earth, but from the spreadsheet that contains the filtered harsh braking data and distance for each individual approach, the number of HBIs at approaches could be counted automatically in addition to the manual count from Google Earth.

3.3.3 Total and Truck Accidents

For the selected locations STATS19 data were acquired from the TRL within a 350m radius from the centre of the roundabouts, for the duration of 11 years. Note that 350m was selected because the majority of HBIs were clustered in roundabouts within this distance (see Figure 3-9). This section illustrates filtration, counting, allocation of total and truck accidents for the selected roundabouts. The procedures illustrated in this section will help identify and understand:

1. The general thesis problem statement is, based on accident trends. This states that accidents trends are decreased and other methods are required to identify locations of high accident risk. In order to identify this trend, the number of accidents and casualties during the 11-year period were computed.
2. Whether the accident data have typical characteristics compared to DFT and previous studies.
3. Whether truck accidents are dangerous at roundabouts compared to other vehicle accidents, which would support using truck HBIs to identify locations of high accident risk.
4. In order to identify percentages of slight, serious, and killed casualties with respect to a number of geometric factors included in model development, which will enhance discussion regarding the modelling results. And,
5. If there are similar characteristics between accidents and HBIs based on position, traffic, and geometric variables, which may support the use of HBIs to investigate accident risk.

In addition, this procedure will supply the number of total and truck accidents, used for modelling purposes illustrated in Chapter Five and Chapter Ten.

Following is the procedure:

- Accident data were uploaded to Google Earth using the Excel to KML program. Firstly, the accident position coordinates were converted from grid easting/northing to latitude/longitude using Grid InQuest Version 6.6.0 available as free download from Ordnance Survey Ireland: "The Grid InQuest software provides a means for transforming coordinates between ETRS89[19] (WGS84)[20] and the National coordinate systems of Great Britain, Northern Ireland, and the Republic of Ireland" (Quest Geo Solutions Ltd, 2004, p.7). The manual describes the procedure used in this study: firstly, the easting and northing from the original STATS19 casualty information Excel sheet are copied to a separate Excel sheet, and then uploaded to the Grid InQuest program in order to convert them to latitude and longitude, with the output appearing in the same or a different Excel sheet. Then the converted points were uploaded to Google Earth and checked to see whether they were located in the selected study roundabouts. Once they had all been checked, then the number of accidents were counted manually using Google Earth.

In order to separate truck accidents from total accidents, so as to upload them separately to Google Earth, the STATS19 Excel sheet for vehicle details was used, one of the columns of which indicates the types of vehicles as shown in Appendix A. As the codes 19, 20, and 21 were for goods vehicles, these codes were filtered. Each filtered truck accident has a reference code, this reference code was used in casualty details to find and highlight truck accidents. With truck accidents highlighted, they were then filtered from other casualty details, then easting and northing, by the same process, were converted to latitude and longitude and uploaded to Google Earth. After uploading them, the numbers of truck accidents for each circulatory and approach of the roundabouts were counted manually. Note that the definition of truck accidents in this study is any accidents involved in these three codes (19, 20, and 21).

- The process of filtering truck accidents was repeated, but this time using the contributory factors sheet of the STATS19 Excel data, in order to get the information about contributory factors for truck accidents.

[19] "The European Terrestrial Reference System 1989" (Quest Geo Solutions Ltd, 2004, p.38).
[20] "The spheroid and datum used to model the geoidal surface for the entire globe. It is the principle datum for GPS since January 1987" (Quest Geo Solutions Ltd, 2004, p.39).

- After the data were imported to Google Earth, in order to compare to the overall statistics illustrated in the literature review in Chapter Two, general accident trends were computed using the STATS19 information regarding collision circumstances and vehicle details; the numbers of casualties by casualty severity type were related to the year, vehicle manoeuvre, month of the year, day of the week, time of the day, road surface condition, light condition, weather condition, traffic control, any special site condition, number of lanes, number of arms, and road class type. It should be noted that STATS19 does not include information on traffic control, number of lanes, and number of arms; this information was added based on the available geometric information for each of the selected roundabouts. The same process was repeated for truck accidents in order to identify general truck accident trends and to compare the results with accidents involving other vehicle types and with total accidents, so as to explore the severity of truck accidents compared to other accident classes. This information helps to identify if the trend for total and truck accidents is falling, which is the problem statement of this thesis.

- In order to identify the main contributory factor that was recorded at the time by police, so as to make comparisons with the previous studies illustrated in Chapter Two, restricted contributory factors for total accidents and truck accidents from the STATS19 information were analysed using the contributory factor code and vehicle numbers. STATS19 has 77 contributory factors, with the contributory factors described by each code illustrated in Appendix A. In each of the selected roundabouts, accidents occurred with a number of contributory factors coded in STATS19, and for each code, the recorded accidents were filtered based on the number of vehicles included in the accidents. This process was repeated for each code and for all of the selected locations. The same process was undertaken to identify restricted contributory factors for truck accidents. The results of this process will lead to identify if accidents have typical characteristics relative to previous studies.

- After the trends were identified, total and truck accidents were characterised based on the distance from the entry line. The ruler from Google Earth was used to compute the distance (i.e. driveway distance). In order to characterise the type of accidents by distance, the data were divided into three groups, one within the circulatory area of the roundabout, one on the approach within 100 m of the entry, and the other more than 100 m from the entry (up to a maximum of 350 m from the roundabout centre), so as to understand how far the accidents occurred away from a given approach's entry line and to compare them with HBIs in order to see whether HBIs have similar characteristics of accidents based on distance from the entry line. These two distances were chosen based on the occurrence of HBIs at approaches to the roundabouts, as it was found that HBIs were clustered within 100 m of the give way lines for most of the locations as shown in Figure 3-10, although some of the HBIs occurred beyond that distance. Note that DMRB TD 16/07 (2007) uses 100 m from the entry line as a measurement guide for the design of roundabouts including speed limit within 100 m on approach, for maximum flare length, and for maximum exit kerb radius. The percentages of total and truck accidents, in addition to HBIs, were then computed based on these distances and compared.

Figure 3-10 Harsh Braking Locations and 100m Distance From Entry Line, East of J21 on the M1 and East of J16 on the M6, Respectively

3.3.4 Geometric Data

Entry width, ICD, and circulatory roadway width were investigated in this study, because Retting (2006) stated that the wider these variables are, the less safe roundabouts will be (see

Table 2-4). These geometric variables were identified using the Ruler tool in Google Earth; its accuracy between two points was checked against the equation (3-1) that calculates the distance between two points in the program, and with original on-site measurements made with measuring tape, as discussed in this section. In addition, signalisation, type of grade and whether approaches were located on A, B, or M roads were identified for the purpose of analysis using Google Earth. Geometric information was identified for modelling purposes. As mentioned in 2.3.4, according to DMRB (TA 78/97, 1997), road marking for in-service roundabouts is considered an important design consideration for efficient movement of traffic and for safer roundabouts, thus road marking for the selected locations was investigated and interpreted (as reported in Chapter Nine).

In order to assess the accuracy of using Google's ruler for measuring geometric dimensions, let us for example choose two points at J21 on the M1. Their latitude and longitude are (52.59867, -1.19537) and (52.59911, -1.19543), and according to Eq. (3-1), the distance between these two points based on their latitude and longitude equals 49m. Uploading the points to Google Earth using Excel to KML using the ruler of Google Earth as shown in Figure (3-11) reveals that the distance between the two points is 49.25m, thereby showing that the use of the ruler of Google Earth is accurate.

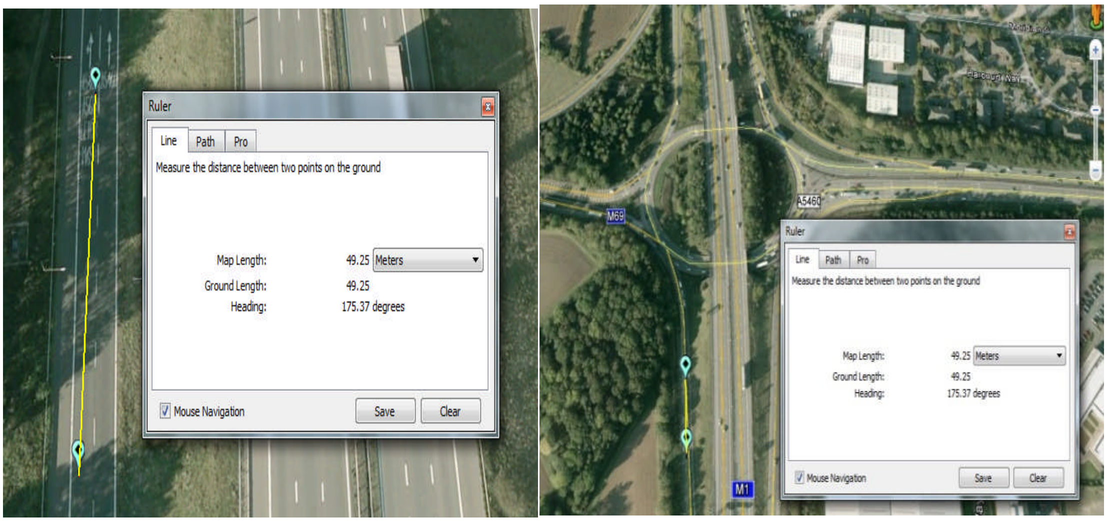


Figure 3-11 Distances Between Two Points in Google Earth (South of J21 on the M1)

The process was checked several times, and Table 3-6 illustrates the results. It is clear that there is only a very small difference between the two distances. In addition, a *t-test* [21] was undertaken in order to explore if the two means are different from each other, the resulted *t* was 0.002 with a *p-value* of 0.998>0.05 indicating that the two means are not different from each other.

Table 3-6 Difference in Distance Using Google Earth's Ruler and Distance Equation

Location and statistical information	latitude	longitude	Distance from Eq. (3-1) (m)	At Google Earth distance (m)	Difference (m)
West of Bromley Heath Roundabout	51.50149	-2.50952	6.53	6.56	0.03
	51.50195	-2.50943			
South of J21 on M1	52.59867	-1.19537	49.077	49.25	0.173
	52.59911	-1.19543			
West of Lodge Lane	52.66769	-2.05048	6.84	6.89	0.05
	52.66775	-2.05046			
J21 on M6	52.68948	-2.10494	27.66	27.67	0.01
	52.68946	-2.10535			
J15 on M4	51.5276	-1.72733	122.92	122.99	0.07
	51.52737	-1.72559			
Mean (μ)			42.61	42.67	

In addition to this, some points in Nottingham (see Appendix B for the selected points for measurement) were selected and their distance was measured manually. Firstly, the distance between two points in Tattershall Drive (see Figure B-1, Appendix B) were measured in a number of points and they all gave a distance of 6.11 m, and for the other distance between two points located in Hassocks Lane Garage (see Figure B-2), the middle of the shoulder was chosen and the distance was measured. For the location illustrated in Figure B-3, the distance was measured at the beginning of each of the shoulders. Table 3-7 shows the results; it is clear from both tables that measuring the distance using the Ruler in Google Earth is

[21] $t-test = \frac{(\mu_1-\mu_2)}{\sqrt{\frac{s_1^2}{n_1}+\frac{s_2^2}{n_2}}}$

Where $\mu_1 - \mu_2$ is the difference between the two sample means
s_1^2 and s_2^2 is the variance of the two sample
n_1 *and* n_2 is the number of observations (Washington et al. , 2011)

acceptable. In addition, a *t-test* was undertaken the resulted *t* was 0.001 with a *p-value* of 0.999>0.05 indicating that the two means are not different from each other.

Table 3-7 Difference in Distance Using Google Earth's Ruler and Original On-Site Measuring Tape

Location and statistical information	On site measuring tape	At Google Earth distance (m)	Difference (m)
Tattershall Drive (Nottingham)	6.11	6.07	0.04
	6.12	6.10	0.02
	28.91	28.93	-0.02
μ	13.7	13.7	

3.3.5 Traffic Data

Traffic data are used as an exposure variable in this thesis in order to explore their influence on HBIs and accidents. Firstly, the Department for Transport provides the traffic data for UK roads and intersections, as illustrated in (DFT, 2016). For the selected roundabouts, firstly the county that the roundabout is located in is chosen, for each approach of the roundabout a code is available this code is reported; then used in the Excel sheet of AADT and average annual daily truck traffic (AADT) that was downloaded from the website for UK roads and intersections in order to filter the selected roundabout approach traffic volume, and this process was undertaken for all the selected roundabout approaches. Note that the codes that are available for the approaches that are located on grade-separated roundabouts cover both approaches and the motorways, and in order to identify traffic volume for these locations (where not all traffic will enter the roundabout), a MATLAB program was written by James Bryce and is shown in Appendix C.

Figure 3-12 shows a sample of a grade-separated roundabout: the red button in the east direction is the traffic count for the motorway going in the east/west direction, so approaches should be computed from this number and the traffic counts on the other routes, using the MATLAB program presented in Appendix C.

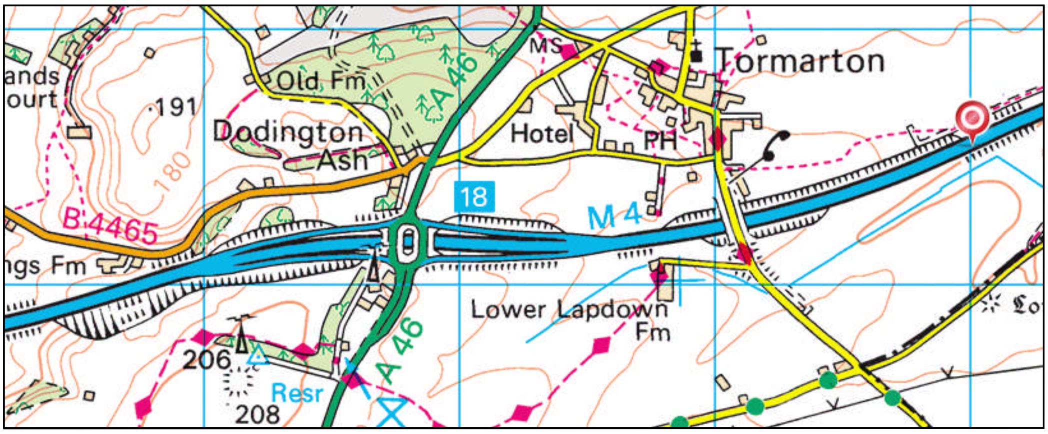


Figure 3-12 Sample of a Grade-Separated Roundabout (J18 on the M4)

This program finds a good solution for the origin destination (OD) matrix using genetic algorithm (ga), a solver which runs a minimisation algorithm to assign values to an OD matrix. A genetic algorithm using a number of runs was chosen in order to get a good and robust solution. This code (in Appendix C) was based on minimising the deviation from the expected proportion of inflow/outflow. The objective of the code is to minimise the difference between the origin flow and the proportion for each destination using the concept of (probability (destination)* volume (origin)) and the assigned traffic volumes. The principal aim of the optimisation is to look at the minimum penalty (Fval1) (i.e. as close to zero as possible) between the computed flow and the origin flow. The algorithm requires a number of simulations; the simulation number should be large enough to get a good solution. First the program has been run for 1000 times, and then it was found that 50 runs is quite enough to get a good solution. Note that the curve shown in Figure 3-13 is terminated before reaching the maximum generation.

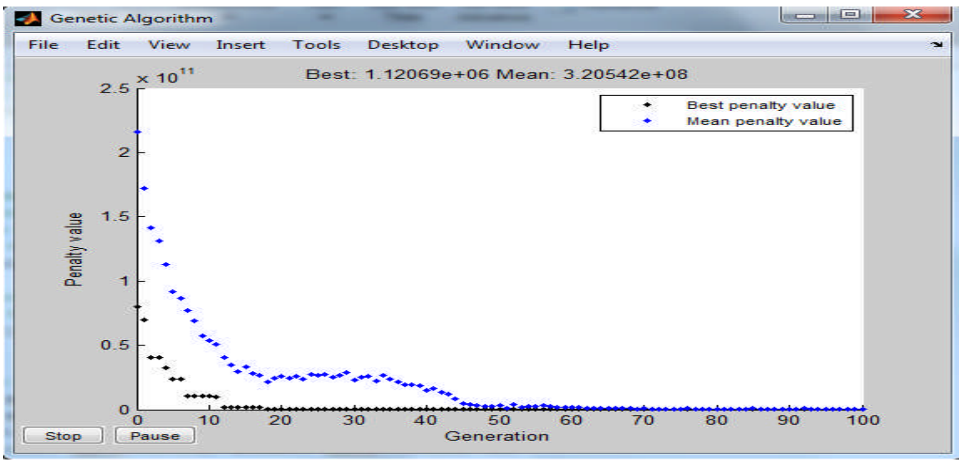


Figure 3-13 A sample Result from the Genetic Algorithm

- First, a code is written for the minimisation function constraining the allowable variation of the inflow (esum1 in the code [esum] = MinErrTr2(OD)). This code reduces the variation in the origin flow that is going in other directions. In this code the original selected roundabout link volumes (inflow and outflow) were entered. Let a, c, e and g be inflows, and b, d, f, and h be outflows, as shown in Figure 3-14.

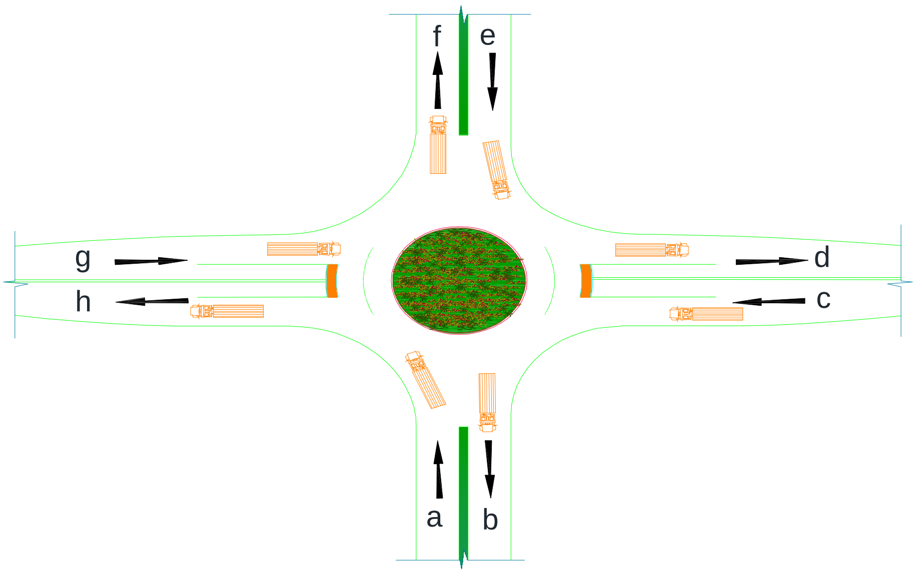


Figure 3-14 Grade-Separated Roundabout with Directions

- To constrain the solution space, a prior matrix was added (i.e. a probability matrix), in order to simultaneously minimise the differences in the total flows in the main directions, and to minimise the differences in the ratios of the directional flow to the total flow (prior matrix). Based on the concept of (probability (destination)* volume (origin)), the prior matrix was observed. A critical assumption for this process is independence between the inflow and outflow (i.e. any given car entering the intersection is equally likely to choose any exit). Thus, before developing the matrix, the probability of destination was identified based on the concept of probability of destination given some origin = probability of destination and defined in the code, as in:

(ad = d/(d+f+h); af = f/(d+f+h); ah = h/(d+f+h) ;) this is for the first row of the matrix.

where:

ad is the proportion of destination from a to d,

and d, f, h is the original outflow (see Figure 3-14).

Then the prior matrix which is based on the concept of (probability (destination)* volume (origin)) is defined in the code and observed, as in:

Pmat = [0 ad*a af*a ah*a;…] for the first row of the matrix.

After this the simulated matrix is developed based on the input variables in the minimisation function. Their definition in the code is:

```
x = zeros(4);
x(1,1) = 0; x(1,2) = OD(1); x(1,3) = OD(2); x(1,4) = OD(3); this is the first row of the matrix
```

The principal aim of the **([esum] = MinErrTr2(OD))** function is to get the lowest penalty value; esum is minimised thus:

esum = sum(sum((x-pmat).^2))+esum1;) this should give a penalty as close as possible to zero.

where esum1 = ∑(a´-a)^2+(b´-b)^2+…….)

where (a´, and b´) are the computed flow,

```
x(1,1) = 0;      x(1,2) = OD(1); x(1,3) = OD(2); x(1,4) = OD(3); a´
x(2,1) = OD(4);
x(3,1) = OD(7);
x(4,1) = OD(10;
   b´
```

And (a, and b) are the original flow.

- In order to run the assigned values to the OD matrix, a code was written based on a minimisation algorithm **([esum] = MinErrTr2(OD))** pertaining to 50 simulations (see Appendix C, Origin/Destination Matrix).
- For the simulation from 1 to 50, a default time was set for the problems and the constraints were entered (e.g. matrix number, minimum and maximum traffic value, and function plot). The (x, fval1) is a statement that solves and runs a genetic algorithm based on the defined first code (**MinErrTr2)**, number of variables (i.e. matrix length (12)), constraints and plot functions, then the penalty value will be stored from the ga function and a default end time. Running this process usually takes 117 to 120 seconds in order to get a solution.

It should be noted that the solutions may not be unique, which is why the minimisation algorithm in the code is set to run *n* times and report percentiles. In order to know whether the solution is stable enough 5^{th}, 50^{th} and 95^{th} percentiles were used to choose a solution. In this study each percentile gave a good solution, because of the lowest penalty value that was acquired in this analysis. Furthermore, the difference between the three percentiles was checked and it was found that the solution is acceptable; for instance, for a roundabout having 10,000 AADT the difference between the 50th and 95th percentile was 100 vehicles, which equates to only 1% difference, and is considered to be practically acceptable. Therefore, the 50th percentile was chosen because it is the average value between the 5th and 95th percentiles, in addition to the computed traffic volume for the separate legs and all legs together being very close to the original value.

For each of the selected roundabouts, available total traffic was added to the statement and the program was run, and the same process was applied to truck traffic in order to get the matrix result for truck traffic for each of the selected grade-separated roundabouts. Table 3-8 is a sample of the origin destination matrix, from the MATLAB program results:

Table 3-8 MATLAB Program Sample Results

D / O	b´	d´	f´	h´
a´	0	OD(1)	OD(2)	OD(3)
c´	OD(4)	0	OD(5)	OD(6)
e´	OD(7)	OD(8)	0	OD(9)
g´	OD(10)	OD(11)	OD(12)	0

When the east/west direction is grade-separated, the approach flow is calculated as:

West approach flow (c´) = OD(4)+ OD(5) (3-2)

East approach flow (g´) = OD(10)+ OD(12) (3-3)

And when the north/south direction is grade-separated, the approach flow is calculated as:

North approach flow (a´) = OD(3)+OD(2) (3-4)

South approach flow (e´) = OD(8)+OD(9) (3-5)

Note that for approaches that are at-grade, original traffic volume was used.

3.3.6 Summary Statistics of the Data for Analysing Accidents and Harsh Braking Incidents

For the purpose of modelling analysis (i.e, analysing total accidents, truck accidents, and HBIs) after the data was filtered, accident and HBI count were obtained, traffic characteristics (AADT, and percentage of truck traffic) were identified for each arm of the selected roundabouts, geometric variables were measured, then based on this information an Excel data set including 70 observations for whole roundabouts and within circulatory lanes, and including 284 observations for approaches was produced. Figure 3-15 shows J21 on the M1 and general accident, HBI, traffic, and geometric information in the selected location; for the other 69 selected roundabouts see Appendix D.

Total traffic AADT (sum of entry traffic)	95973
Truck %	8.6
Inscribed circle diameter (m)	168
Circulatory roadway width (m)	10.6
Average entry width (m)	11.8
Number of lanes	3
Type of signalisation	Partially signalised
Type of grade	Grade-separated
Total accident (entry +circulatory lanes)	142
Truck accident (entry +circulatory lanes)	52
Harsh braking incident (entry +circulatory lanes)	269

Figure 3-15 General Information of J21 on the M1

As the files that contain all the information for different categories of roundabouts are large, the summary statistics for the selected locations are shown in Tables 3-9a to c, for whole roundabouts, within circulatory lanes, and at approaches. The summary statistics include dependent and independent variables that are used to build the models illustrated in Chapter Five and Chapter Seven. The variance and mean of the dependent variables illustrated in Table 3-9a to c, identifies that NB distribution is suitable for the three dependent variables examined in this study, for more details see Section 3.5.2, These variables are selected in this study because previous studies illustrated in Section (2.3.6) have shown that they have significant effect on accidents whereas, signalisation, percentage of truck traffic, and type of grade were used in this study for the first time to explore their effect on accidents and HBIs at roundabouts.

Table 3-9a Summary Statistics of the Accident, HBI, Geometric and Traffic Variables for Whole Roundabouts

Roundabout category	Variable	Min	Max	Mean	Variance
Whole roundabouts	*Accident and HBI characteristics (Dependent variable)*				
	11 -year total accidents numbers	5	170	60.50	2061
	11 -year Truck accidents numbers	0	54	14.10	199
	2 -year HBIs numbers	0	764	152.6	32472
	Geometric characteristics(independent variable)				
	Lane number (1 if lane number is 2; 0 if 3)	0	1	0.55	0.25
	Number of arms (1 if arm number is 3; 0 otherwise)	0	1	0.17	0.14
	Number of arms (1 if arm number is 4; 0 otherwise)	0	1	0.55	0.25
	Number of arm (1 if arm number is 5; 0 otherwise)	0	1	0.17	0.14
	ICD (m)	38	280	158.29	4349
	Circulatory lane width (m)	6	15	10.65	3
	Entry width (m)	7	14	9.99	4
	Traffic signal (1 if signal; 0 otherwise)	0	1	0.29	0.20
	Traffic signal (1 if un-signal; 0 otherwise)	0	1	0.40	0.24
	Type of grade (1 if roundabout is grade-separated; 0 otherwise)	0	1	0.73	0.20
	Traffic characteristics (independent variable)				
	AADT	11170	137773	50840.86	766834680
	Percentage of average annual daily traffic of trucks	2	23	6.97	11

Table 3-9b For Circulatory Lanes

Within circulatory	*Accident and HBI characteristics (Dependent variable)*				
	11 -year total accident numbers	0	108	18.40	392
	11 -year truck accident numbers	0	28	4.50	36
	2 -year HBIs numbers	0	231	19.70	1648
	Geometric Characteristic s(independent variable)				
	Lane number (1 if lane number is 2; 0 if 3)	0	1	0.57	0.25
	ICD (m)	38	280	162.40	4143
	Circulatory lane width (m)	6	15	10.67	3
	Traffic signal (1 if is signal; 0 otherwise)	0	1	0.30	0.21
	Traffic signal (1 if un-signal; 0 otherwise)	0	1	0.43	0.25
	Type of grade (1 if roundabout is grade-separated; 0 otherwise)	0	1	0.73	0.20
	Traffic Characteristics (independent variable)				
	AADT	11170	137773	50840.86	766834680
	Percentage of average annual daily traffic of trucks	2	23	6.97	11

Table 3-9c For Approaches

At approaches	*Accident and HBI characteristics(dependent variable)*				
	11 -year total accident numbers	0	54	9.40	83
	11 -year number of truck accident numbers	0	15	1.90	6
	2 -year HBIs numbers	0	325	31.10	2970
	Geometric Characteristics (independent variable)				
	Lane number (1 if lane number is 2; 0 if 3)	0	1	0.61	0.24
	Approach entry width (m)	5.26	20	9.99	6.00
	Traffic signal (1 if is signal; 0 if un-signal),	0	1	0.50	0.25
	Type of grade (1 if roundabout is grade-separated; 0 if at-grade)	0	1	0.74	0.19
	Traffic Characteristics (independent variable)				
	AADT	1903	51201	12724.04	54499977
	Percentage of average annual daily traffic of trucks	1	18	7	9

Table 3-10 illustrates the list of continuous[22] and categorical[23] variables used to build the models in this study. Washington et al. (2011) stated that in regression analysis, in the case of having indicator variables, n-1 must be generated to characterise all n levels; if not it will cause collinearity with the constant of the model. For instance, in this study traffic signalisation in the whole roundabout and within the circulatory lanes can be signalised, un-signalised, or partially signalised, and a categorical variable was used only for signalised and un-signalised, as if we have a three-category variable we cannot estimate three indicators, since they will sum to one and be collinear with constant. Therefore, for a signalisation indicator (1 if signalised; 0 otherwise) and (1 if un-signalised; 0 otherwise), the beta (regression coefficient) will tell us the effect relative to partially signalised intersections. The same approach is taken for the number of arms, as there are three, four, five and six-arm roundabouts, and for number of lanes, and other categorical variables.

Table 3-10 List of Continuous and Categorical Variables Used to Build Models

Variable	**Type**
AADT	Continuous
Percentage of average annual daily truck traffic	Continuous
Number of traffic moving lanes for whole roundabout (1 if lane number is 2; 0 if 3)	Categorical
Circulatory traffic lane number (1 if lane number is 2; 0 if 3)	Categorical
Number of lanes at approaches (1 if lane number is 2; 0 if 3)	Categorical
Number of roundabout arms (1 if arm number is 3; 0 otherwise), (1 if arm number is 4; 0 otherwise); (1 if arm number is 5; 0 otherwise)	Categorical
Roundabout ICD (m)	Continuous
Roundabout circulatory lane width (m)	Continuous
Average entry width for whole roundabout (m)	Continuous
Approaches entry width (m)	Continuous
Whole and circulatory traffic signal (1 if signal;0 otherwise), (1 if un-signal;0 otherwise)	Categorical
Approach traffic signal (1 if signal;0 if un-signal)	Categorical
Type of grade (1 if roundabout is grade-separated;0 if at-grade)	Categorical

Note that in this study, AADT is entered to the model as natural logarithm (ln), because previous studies in accident modelling stated that ln(AADT) reduces large variation of AADT across the observations (Wang et al., 2009; Prato et al., 2015). Biernbaum et al. (2008) stated that using natural logarithm of AADT, the estimated regression coefficient read

[22] "If a variable can take on any value between its minimum value and its maximum value, it is called a continuous variable" **(**Stattrek, 2016**).**
[23] "Categorical variables take on values that are names or labels" (Stattrek, 2016)

as elasticity[24] at mean. Venkataraman et al. (2014) and Kamińska (2014) stated that in accident modelling using the natural logarithm of AADT, the fitness of the model is improved. However, Šenk and Ambros (2011) and Miaou and Lord (2003) stated that the advantage of using ln(AADT) rather than AADT gives zero predicted accident number when AADT is zero. In addition, using ln(AADT) allows the relationship to be nonlinear between traffic volume and predicted number of accidents (Kowdla, 2004; Miaou & Lord, 2003; Alluri, 2008). In addition, all the studies predicting accidents at roundabouts presented in Table 2-5 used ln(AADT).

3.4 Analysis of Variance (ANOVA)

In order to determine the significance of AADT and percentage of truck traffic on the dependent variables (total accidents, truck accidents, and HBIs) based on different numbers of arms, numbers of lanes, traffic control type, and type of grade, the relationship between dependent variables with AADT and the percentage of truck traffic was identified using linear regression analysis, including analysis of variance (ANOVA). This process helps explore how the dependent variables (total accidents, truck accidents, and HBIs) associated with the traffic characteristics in each of the selected roundabouts based on different geometric characteristics before building a NB model. This regression analysis was identified for whole roundabouts, within circulatory lanes, and at roundabout approaches. This analysis gives ideas and reasons behind using the geometric and traffic variables in the random-parameters NB models.

Furthermore, in order to explore how HBIs influence the occurrence of total and truck accidents, HBIs were related to truck and total accidents using linear regression analysis, for each of the roundabout categories.

SPSS was used to test the significance of the coefficient of determination (R^2), in which the model summary gives information about the significance of R^2 using the available confidence coefficient p-value[25] and F-test. The confidence coefficient or the probability can be estimated from the confidence intervals[26]. The confidence intervals showed as a percentage

[24] Elasticity is defined as the impact of an independent variable on a dependent variable and it estimates this impact and explains the influence of 1% change in the independent variable on the predicted dependent variable (Washington et al., 2011).

[25] "The smallest level of significance confidence interval (α) that leads to the rejection of the null hypothesis" (Washington et al., 2011, p. 445)

[26] Confidence interval is "a calculated range of values known to contain the true parameter of interest over the average of repeated trials with specific probability". So if drawing samples for so many times with the same level of estimated (independent) variables and computing test statistic (mean, constant, et..), then the correct

and three levels were used to calculate the confidence coefficient probability p-value (Singpurwalla, 2016):

$$p\text{-value} = 1 - 0.90 = 0.1 \text{ (90\% confidence)} \quad (3\text{-}6)$$

$$p\text{-value} = 1 - 0.95 = 0.05 \text{ (95\% confidence)} \quad (3\text{-}7)$$

$$p\text{-value} = 1 - 0.99 = 0.01 \text{ (99\% confidence)} \quad (3\text{-}8)$$

The F ratio can be illustrated with respect to R^2 (Williams, 2015):

$$F = \frac{R^2 \times n-k-1}{(1-R^2) \times k} \sim F(k, n-k-1) \quad (3\text{-}9)$$

k = the number of independent variables or degrees of freedom of the independent variables without the intercept and is called first degree of freedom (df1); also it is called Numerator degree of freedom

n = the total number of observations

$n - k - 1$ is second degree of freedom (df2) or residual degree of freedom; also it is called Denominator degree of freedom

When R^2 and F are approximately zero then the result is a null hypothesis. If the value of F is statistically significant, this indicates that the variation in the dependent variable can be explained by the variation of independent variables, in other words, R^2 can be used to define how much the mean of the dependent variable can be explained or affected by the independent variables.

3.5 Model Estimation

3.5.1 Overview

Random parameters NB models were used to identify the significance of traffic and geometric characteristics on HBIs in order to achieve the first objective of this study (characterise incidence of HBIs at a number of roundabouts). The same models with the same traffic and geometric characteristics were developed for total and truck accidents in order to achieve the second objective of this study (compare the harsh braking characteristics to

sample parameter probably lie in the (1-confidence interval (α))% this is called conditional on true null hypothesis (Washington et al. , 2011, p.427) factors known to influence accident rates). This will help explore if accident and HBI numbers are related to the same traffic and geometric factors and hence if HBIs can be expected to reflect accident risks. In order to identify if HBIs can be used directly for accident prediction purposes at the roundabouts to supplement accident data, a NB model was identified between accidents and HBIs along with traffic and geometric characteristics, the results of which could be useful for the future design of roundabouts with the objective of making them safer.

The following sections describe the methodology to identify

- The relationship between accidents with traffic and geometric characteristics, and the relationship between HBIs with traffic and geometric characteristics for whole roundabouts, within circulatory lanes, and at approaches to the roundabouts, in addition for grade-separated and at-grade roundabouts.
- The relationship between total and truck accidents with HBIs along with traffic and geometric characteristics for whole roundabouts, within circulatory lanes, at approaches, for grade-separated, for at-grade, and for different approach category (i.e., for three lane approaches, for two lane approaches, for approaches located in M-class roads, for approaches located in A-class roads, for signalised approaches, and for un-signalised approaches).

3.5.2 Model Description

There are a number of statistical methods available to predict the number of accidents on roadway segments including roundabouts and intersections. The summary statistics illustrated in Section 3.3.6 show that for dependent variables (total accidents, truck accidents, and HBIs) the mean is less than the variance for all roundabout categories (see Tables 3-9a to c). This indicates that the data is over-dispersed and as discussed in Section 2.1.4 for such dispersion the NB distribution is more suitable for predicting count data, for this reason NB models were used to predict total accidents, truck accidents, and HBIs. In this study the random parameters model is applied for the first time to predict accidents and HBIs at roundabouts, because as described in Section 2.1.4, using traditional NB models (which allow parameter to be fixed across observations) to predict accidents at road sections including intersections and roundabouts would lead to biased results and wrong conclusions may be drawn as stated by Lord and Mannering (2010). The result obtained using the random parameters NB model is compared with that of the fixed parameters NB model. As described in Section 2.1.4, random-parameters models allow one or more variables to vary across the observations and this can be indicated by the SD of the random variables (if the SD of the distributed variable is statistically different from zero then it is considered random, and if not it remains fixed across the observations). The model is based on a number of traffic and geometric variables described in Section (3.3.6) for each roundabout category.

The methodological approach behind the application of random-parameters models to count data is illustrated in detail in Section 2.1.5 and, as described in that section, in order to let variable effects to vary across the observations using random parameters count-data models, the predicted mean of the variables are written as illustrated in Eq. (2-8).

The random-parameters and fixed-parameters NB count data models were applied to the dependent variables using *LIMDEP* software, which is an econometric and statistical software package that provides a programming language to specify, estimate and analyse random and fixed-parameters NB models. This section describes the command statement used to predict accidents and HBIs, illustrating the procedure behind the random parameter; for more details about the procedure see Appendix E. Halton draws and marginal effects used in the statement are explained, and all the parameters used in the *LIMDEP* program are described. A more detailed description of the commands and statements illustrated in this section is given by Greene (2007).

Let:

negbin = specification for NB model.

Lhs = specification includes dependent variable; let (y) be the dependent variable (total accident or truck accident or HBI numbers) based on the model to be developed.

Rhs = specification, including the independent variables; let whole roundabout x1 to x11 be the geometric and traffic variables in which (x1 = two-lane indicator, x2 = three-arm indicator, x3 = is four-arm indicator, x4 = is five-arm indicator, x5 = is ICD, x6 = is circulatory roadway width, x7 = is entry width, x8 = is signalised indicator, x9 = is un-signalised indicator, x10 = is the percentage of truck traffic, and x11 = is ln(AADT)). The variable *one* is used for the constant term, as described by Greene (2007), who stated that in order for a model to contain a constant term the variable *'one'* with the other Rhs variables must be included.

In order to compute the predicted value, **keep = yfit170** command is used to compute the prediction values for the estimated model and keep them as new variables named **yfit170** (Greene, 2007). The computed predicted value is compared to the actual value in order to identify the accuracy and fitness of the random parameters models to the data relative to the fixed parameters model.

Rpm: description of the random parameters models

Pts = the number of replications (draws) for the estimated simulation; the program default value is 100, but we can change this value.

Halton = specification of Halton sequences or draws for simulation-based estimators (see Section 2.1.5.1, and later in this section).

Fcn = the specification of the random parameters. The basic form is Fcn = parameter label (type), in which the ‘parameter label’ is defined as a variable name that has been used in Rhs specification, and ‘type’ is one of the distributions defined in the later paragraph (Greene, 2007). It should be noted that the random parameters model in *LIMDEP* has a combination of fixed and random parameters: the FCN specification is used only for the parameters that are considered random, for a fixed-parameter model this statement will be removed before running the program.

Marginal effect = displays estimated marginal effects (more detail concerning this is given in Section 2.1.5.2, and later in this section).

Then from the above specifications a fixed and random-parameters NB command that is used to predict accidents and HBIs can be written as:

Fixed-parameters NB model command:

```
--> negbin;lhs = Y;rhs = one,x5,x9,x10,x11
    ;rpm;pts = 200;halton
    ;marginal effects$
```

Random-parameters NB model command:

```
--> negbin;lhs = Y;rhs = one,x5,x9,x10,x11
    ;rpm;pts = 200;halton
    ;fcn = x10(n);marginal effects$
```

In the random-parameters model statement shown, in the fcn statement, for instance x10 (n), the variable (n) is for normal distributions, and in this study all the random parameters were found to statistically fit in a normal distribution. However, there are other distributions, for instance "lognormal (which restricts the impact of the estimated parameter to be strictly positive or negative), Weibull, uniform and triangular" (Anasatasopoulas & Mannering, 2009, p.155). Note that for the random parameter (i.e. normally distributed), the tool in Stattrek (2016) was used in order to identify the probability that a normal random variable has chance to increase or decrease in accidents and HBIs as a percentage. Firstly, the standard score (z) illustrated in the calculator as a value of zero was used (i.e. area under normal distribution), then the resultant value of mean and SD of the random parameters examined from the model was uploaded to the calculator to give the cumulative probability $P(Z \leq z)$[27] for the random parameters. The probability will be between zero and one, by which the uncertainty associated with the event is quantified (e.g. the probability that a two-lane indicator is associated with more rather than fewer accidents would be 0.33, which means 33% of two-lane roundabouts resulted in more accidents, and 67% resulted in fewer).

Estimating random and fixed-parameters NB model requires a maximum likelihood simulation. As discussed in Section 2.1.5.1, Halton draws were used by previous researchers (Anastasopoulos & Mannering, 2009; El-Basyouny & Sayed, 2009; Garnowski & Manner, 2011; Ukkusuri et al., 2011; Venkataraman et al., 2014) to overcome the problem of maximum likelihood estimation for the random parameters data that is independent, thus this technique with 200 draws was applied in the current study, whereby (based on the models developed) the maximum number of random parameters is three, which means the model requires three-dimensional integration to estimate a good approximation. And Bhat (2003) found that 150 Halton draws gives a good approximation for dimensions of less and more than five, when it is compared to 500 random draws.

Marginal effect in the model statement, as described in Section 2.1.5.2, Eq. (2-10), gives the predicted change in the dependent variable with respect to a one-unit change in the independent variable over a time period. For instance, as the accident data covers 11 years, the expected change in accidents will be over 11 years, by a one-unit change of the independent variable (e.g. if the marginal effect for ICD (metre) was 0.2, a one metre increase in ICD would be associated with an increased average of 0.2 accidents over an 11-

[27] Is a value referring to the probability that a randomly selected variable will be less than or equal to a specified value usually varies from zero to one (Stattrek, 2016).

year period). As discussed in Section 2.1.5.2, *LIMDEP* software computes marginal effects with respect to the mean of the independent variable (see Eq. (2-11)) instead of taking individual means then dividing by the number of observations as in Eq. (2-10).

<u>The procedure for getting a random-parameters NB model:</u>

1. Firstly check all the variables to get a good fixed-parameters NB model: any variables that are insignificant will be removed from the model. A good fixed-parameter NB model is acquired by adding the first variable, if it is found to be significant it will remain in the model, if not it will be removed and the second variable will be added. This process continues until all the variables have been checked and only the significant ones remain in the model.

2. After building a good significant fixed-parameters model, then all significant parameters in the fixed model are tested as a random variable in order to see if any independent variables are distributed randomly; the variables that were found to be insignificant in the fixed-parameters model are also tested in the same way. A parameter is random when the SD of the parameter distribution is statistically different from zero; if the estimated SD of the parameter distribution is not statistically different from zero then the parameter is fixed across the roundabouts.

Note that when a given variable's:

- Mean and SD are insignificant; it is removed from the model (see orange circles outlined in *LIMDEP* output below). Note that the significance of the parameter is indicated by the *t*-statistic (*b/St.Er.*). Usually, a *t*-test is used to test the significance of the coefficients; three *t*-statistics are available for testing the significance of the variables (1.65, 1.96, and 2.58 for 90%, 95%, and 99% significance level, (Washington et al., 2011)).

```
+--------+--------------+----------------+--------+--------+----------+
|Variable| Coefficient  | Standard Error |b/St.Er.|P[|Z|>z]| Mean of X|
+--------+--------------+----------------+--------+--------+----------+
---------+Nonrandom parameters
 Constant|    -.75437696      1.37389016     -.549   .5829
 X2      |    -.34701130       .22634492   -1.533   .1252    .17142857
 X5      |     .00359150       .00127928    2.807   .0050   158.285714
 X9      |    -.52912729       .14523375   -3.643   .0003    .40000000
 X10     |     .05828811       .03211237    1.815   .0695   6.97457143
 X11     |     .37379924       .11937370    3.131   .0017   10.6753286
---------+Means for random parameters
 X1      |    -.08766474       .14476267     -.606   .5448    .55714286
---------+Scale parameters for dists. of random parameters
 X1      |     .00776991       .08445208      .092   .9267
---------+Dispersion parameter for NegBin distribution
 ScalParm|    4.37305090      1.02780736     4.255   .0000
```

- Mean is significant and SD is insignificant (not statistically different from zero), the variable is fixed across the observation (see orange circles outlined in *LIMDEP* output below).

```
+--------+--------------+----------------+--------+--------+----------+
|Variable| Coefficient  | Standard Error |b/St.Er.|P[|Z|>z]| Mean of X|
+--------+--------------+----------------+--------+--------+----------+
---------+Nonrandom parameters
 Constant|    -1.04382707      1.29591976     -.805   .4205
 X5      |      .00340901       .00125552     2.715   .0066   158.285714
 X9      |     -.55005249       .14393184    -3.822   .0001    .40000000
 X10     |      .05934036       .03285806     1.806   .0709   6.97457143
 X11     |      .39960419       .11012198     3.629   .0003   10.6753286
---------+Means for random parameters
 X2      |     -.39452195       .21396122    -1.844   .0652    .17142857
---------+Scale parameters for dists. of random parameters
 X2      |      .22319755       .17414484     1.282   .2000
---------+Dispersion parameter for NegBin distribution
 ScalParm|     4.46850474      1.03043312     4.337   .0000
```

- Mean is statistically not insignificant and SD is statistically different from zero (i.e. significant), the variable is considered random across the observation (see orange circles outlined in *LIMDEP* output below).

```
+--------+--------------+----------------+--------+--------+----------+
|Variable| Coefficient  | Standard Error |b/St.Er.|P[|Z|>z]| Mean of X|
+--------+--------------+----------------+--------+--------+----------+
---------+Nonrandom parameters
 Constant|     -.41840236      1.44755974     -.289   .7726
 X2      |     -.52425659       .24299949    -2.157   .0310    .17142857
 X5      |      .00323736       .00127543     2.538   .0111   158.285714
 X9      |     -.56216442       .13966892    -4.025   .0001    .40000000
 X10     |      .05720841       .02899103     1.973   .0485   6.97457143
 X11     |      .35618983       .12434136     2.865   .0042   10.6753286
---------+Means for random parameters
 X3      |     -.17307971       .17482546     -.990   .3222    .55714286
---------+Scale parameters for dists. of random parameters
 X3      |      .13901017       .08321219     1.671   .0948
---------+Dispersion parameter for NegBin distribution
 ScalParm|     4.65211165      1.22076421     3.811   .0001
```

- Mean and SD are both significant, the variable is considered random across the observation (see orange circles outlined in *LIMDEP* output below).

```
+--------+--------------+----------------+--------+--------+----------+
|Variable| Coefficient  | Standard Error |b/St.Er.|P[|Z|>z]| Mean of X|
+--------+--------------+----------------+--------+--------+----------+
---------+Nonrandom parameters
 Constant|    -1.45568045       .85745978    -1.698   .0896
 X5      |      .00498050       .00081314     6.125   .0000   158.285714
 X9      |     -.57702925       .09961131    -5.793   .0000    .40000000
 X11     |      .40280665       .08136405     4.951   .0000   10.6753286
---------+Means for random parameters
 X10     |      .06047130       .01372978     4.404   .0000   6.97457143
---------+Scale parameters for dists. of random parameters
 X10     |      .05478512       .00632302     8.664   .0000
---------+Dispersion parameter for NegBin distribution
 ScalParm|     10.3498499      2.32421817     4.453   .0000
```

The detailed procedure concerning the *LIMDEP* output is illustrated in Appendix E. It should be taken into account that once the random-parameters model is estimated, a separate parameter is estimated for each observation, therefore it cannot be written as an equation since each observation has its own β if the parameter is random.

3. Then the estimated final random-parameter model is run as a fixed model by removing the FCN statement for comparison.

4. The same procedure (steps 1, 2 and 3) was used to estimate models for grade-separated and at-grade roundabouts based on total accidents, truck accidents and HBIs. In addition, the same procedure was applied to total and truck accidents when they are related to HBIs, along with traffic and geometric variables for whole roundabouts, within circulatory lanes, and at roundabout approaches and for different approach categories (number of lanes, signalisation, and road class).

3.5.3 Model Evaluation

In order to check how the independent variables are related to each other, collinearity tests are carried out before building the model. Collinearity happens if there is a strong correlation between two independent variables in a model, (O'Brien, (2007)). When collinearity occurs it increases the variance of the independent variables that could be estimated to build a model. In case collinearity and multicollinearity, the estimated dependent variable is usually un-stable because of high standard errors and a reliable and significant regression coefficient for the estimated variable is difficult to obtain (Washington et al. 2011). For instance, when there is collinearity in the model it will make the independent variable statistically insignificant because of high standard errors while it should be significant. For this purpose, variation inflation factors (VIF) have been used to establish the degree of collinearity between independent variables, VIF indicate the R^2 effect on the variance of the estimated coefficient for independent variables in a regression model (O'Brien, (2007)). The tolerance of an independent variable is (O'Brien, (2007)):

$$\text{Tolerance} = 1 - R^2 \qquad (3\text{-}10)$$

Where tolerance measures the proportion of variance between two independent variables, and as defined previously in Section 3.4, where R^2 explains the mean of one variable by the variance of the other variable (in this case the mean of an independent variable by the variance of the other independent variable). The unexplained variance can be identified by 1-R^2: the tolerance rate varies between 0 and 1, and the lower the tolerance, the higher the existence of collinearity and multicollinearity.

VIF = 1/Tolerance (3-11)

Collinearity occurs at a tolerance of < 0.20 or 0.10 this leads to a VIF of 5 or 10 (O'Brien,, 2007).

Variation inflation factors were identified using SPSS software. Firstly, the correlation between all study parameters (geometric and traffic variables) is estimated in order to identify R^2, then equations (3-10) and (3-11) are used to identify the collinearity between the independent variables.

Then, after the variables have been selected and models have been developed, assessments are made based on statistical approaches as a part of the process of selecting the most appropriate and best fitting models. The model is first evaluated according to the significance of the variables included in the model. The estimated coefficient β for each of the independent variables in the model should be statistically significant.

The likelihood ratio test was used in order to compare the fixed and random-parameter models using the likelihoods at convergence. The test statistic is chi-square(χ^2):

$$\chi^2 = -2[LL(\beta_F) - LL(\beta_{RP})] \quad (3\text{-}12)$$

where $LL(\beta_F)$ is the log-likelihood at convergence of the fixed-parameters NB model, and $LL(\beta_{RP})$ is the log-likelihood of the random-parameters NB model (Anasatasopoulas & Mannering, 2009; Washington et al., 2011). Calculated χ^2 with the degrees of freedom which are equal to the number of variables that are randomly distributed in the random-parameters models were used in order to identify the significance of the random-parameters model relative to the fixed-parameters model from this website (Stattrek, 2016).

The McFadden ρ^2 statistic is used in addition to χ^2 to test overall fit of the model and for the purpose of comparison with other models. The McFadden ρ^2 statistic is computed as (Washington et al., 2011):

$$\text{McFadden } \rho^2 = 1 - \frac{LL(\boldsymbol{\beta})}{LL(\boldsymbol{C})} \quad (3\text{-}13)$$

where $LL(\boldsymbol{\beta})$ is the log-likelihood at convergence with estimated parameter $\boldsymbol{\beta}$, and $LL(\boldsymbol{c})$ is the log-likelihood at constant only.

In addition, the two models were also compared using the relationship between actual mean values and predicted values of the response variables for both the random and fixed-parameter models.

Moreover, for the models that included HBI along with traffic and geometric variables, Akaike information criteria (*AIC*) were used to compare the results to the models that did not include HBI as an input variable. *AIC* is calculated as (Washington et al., 2011):

$$AIC = 2Q - 2LL(\boldsymbol{\beta}) \tag{3-14}$$

where: Q is the number of the predicted variables including constant, and $LL(\boldsymbol{\beta})$ is the log-likelihood at convergence. The lower value of AIC are chosen because the lower value of $-2LL(\boldsymbol{\beta})$ represents a better fit of the model. Note that $LL(\boldsymbol{\beta})$ is a negative value.

3.6 Summary

This chapter gives a data description and describes the methodology that was undertaken to explore the feasibility of using truck sensor position data for analysing roundabout accident risk. It provides detailed information about the data sources and the procedures that were undertaken to analyse the data. The definition of HBI by Microlise Ltd. is presented and is compared with previous studies and with tests undertaken using smartphone accelerometers. Counting, filtration, and allocation of HBIs are illustrated. Filtration of truck accidents from total accidents is presented for the purpose of analysis. In addition, the reason for choosing two years of HBIs relative to 11 years of accidents is shown. Then the geometric information computed from Google Earth is compared with the distance equation and with on-site measuring tape and is illustrated. Estimation of traffic data to the correct approaches is discussed in this chapter and the detailed procedure is described.

For the purpose of analysing accidents and HBI numbers a summary statistic of the traffic and geometric characteristics is presented. In addition, from summary statistics for the dependent variables the reason behind choosing NB models for predicting accidents and HBIs is shown. Moreover, a detailed summary of the generation procedure for the econometric models used to predict total accidents, truck accidents, and HBIs was presented.

The following chapters present the results acquired from the procedures illustrated in this chapter.

Chapter 4 General Accident Analysis Trends

4.1 Introduction

This chapter describes the accident analysis for the selected locations. The locations were selected to include those with high and low numbers of HBIs. The main object of this chapter is to find the trend of total and truck accidents, in order to explore if the accident trend is falling, and to find how total and truck accidents change due to different circumstances related to the road environment, including weather conditions, lighting conditions and road surface conditions, time of the day and day of the week, geometric layout including traffic control, number of arms, and number of lanes. These factors will be examined in order to compare truck and total accidents, and to examine the trends of accidents compared with previous studies. The other goal is to find out the main geometric and traffic factors influencing these accidents. For example, it is important to see at what distance accidents have occurred away from approaches and within circulatory lanes in order to make a comparison with the HBIs which have occurred at approaches and within circulatory lanes. General accident trends and accidents' restricted contributory factors will be studied, followed by a characterisation of the type of accidents by distance from the entry line. In addition, the relationship between total and truck accidents to traffic with respect to different geometric characteristics will be explored using linear regression, for the whole roundabouts, within the circulatory lanes, and at approaches. This will be illustrated in the later sections, and a summary of the work will be presented in the final section.

4.2 General Accident Trends

The STATS19 data form (see Appendix A) records accidents categorised by different collision and vehicle circumstances, for instance road surface conditions, light conditions, weather conditions, special conditions on site, skidding and overturning, and vehicle manoeuvres. Accident trends through an 11-year period were investigated, and accident trends according to year, months of the year, day of the week, and hours of the day were found, to identify general characteristics of accidents within the selected locations and to enable comparisons with previous studies. According to STATS19 data, 5,520 casualties of all vehicle types around the selected locations (entry, exit, and circulatory lanes) were recorded during the 11 years from 2002 to 2012. Table 4-1 illustrates the number of accidents and the number of vehicles involved in total accidents, truck accidents, and accidents involving other types of vehicle, respectively. Table 4-2 illustrates the number and percentage of casualties recorded in each type of accident. Table 4-1 shows that a lower number of trucks are involved in accidents, but a comparison of truck accidents to other types of vehicle accidents in Table 4-2 shows that more fatalities occur in truck accidents (2.10%) than in accidents involving other types of vehicle (1.07%). This shows that truck accidents are more dangerous because of their size, weight, and manoeuvrability as identified by the DFT (2014), Trucks V, (2013), US Department of Transportation (2014), Carstensen et al. (2001), Grygier et al. (2007), and Kennedy (2007). Trucks are an important factor for consideration when designing a road network, including roundabouts, even if the percentage of trucks is not high compared with other vehicle types because when truck accidents occur, they account for more severe accident outcomes. The size, weight and the configuration of a truck are all potential causes of severe accidents. For this purpose an investigation is necessary based on feasibility of truck position data to study roundabout accident risk.

Table 4-1 Accident Numbers and Number of Vehicles Involved in Different Types of Accidents

All accidents	Accidents involving trucks	Other type vehicle accidents	Total number of vehicles involved	Number of trucks involved	Number of other type vehicles involved
5520	1468	4052	11510	3289	8221

Table 4-2 Casualties for Different Types of Accidents

	Number of all casualties			Number of casualties in accidents involving trucks			Number of casualties involving other types of vehicles		
	Fatal	Serious	Slight	Fatal	Serious	Slight	Fatal	Serious	Slight
Numbers	84	692	7032	43	173	1834	41	519	5198
Percentage	1.07	8.86	90.07	2.10	8.40	89.50	0.7	9	90.3
Total casualties	7808			2050			5758		

The following subsection illustrates general accident trends during the 11-year period according to the collision and vehicle circumstances. Note that the casualties illustrated in the following sections were recorded within 350m of the roundabouts' centres.

4.2.1 Accident Trends Through the 11-Year Period: 2002–12

Accidents resulting in fatal, serious, and slight injuries in the selected locations decreased throughout the 11-year period. As seen in Figure 4-1, 2002 and 2003 saw the highest number of casualties. After that there is a fluctuation in the number of casualties till 2007, after which the number of casualties decreased. During the period the number of casualties decreased by 37%, an observation which is in line with previous studies for road sections presented in Section 2.1.4 (DFT, 2014; Trucks V, 2013; US Department of Transportation, 2014) and is in line with the Kennedy (2007) study for accident trends at roundabouts. In addition, this proves the general thesis problem statement, in which general accident trends are falling, and other methods are required to identify locations of high accident risk.

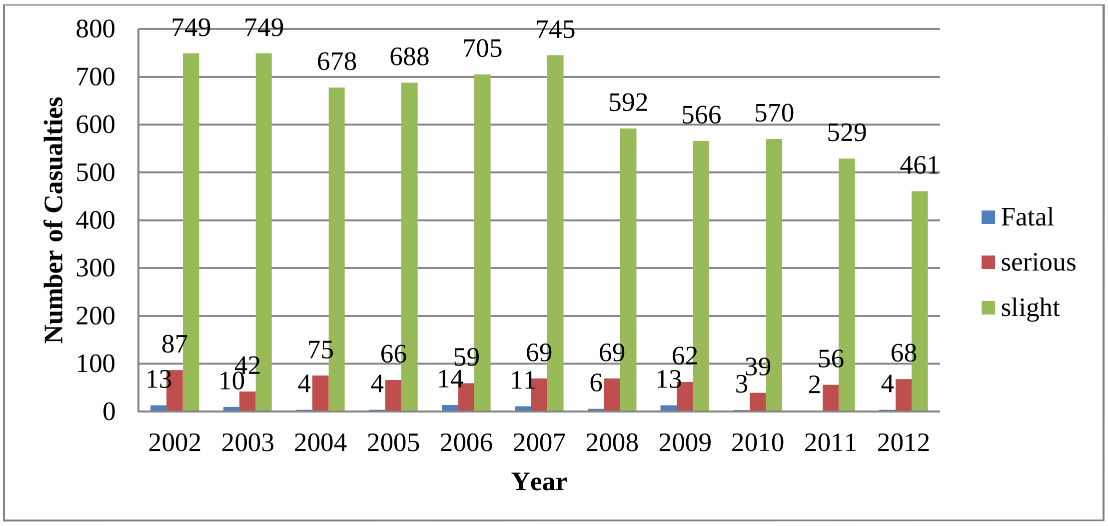


Figure 4-1 Fatal, Serious, and Slight Accidents 2002–12

Fatal, serious, and slight casualties from truck accidents in the selected locations decreased through the 11-year period. As shown in Figure 4-2, there is a fluctuation in the number of casualties during the period. Overall the number of casualties decreased by 35%, and 2003 shows the highest number of casualties associated with truck accidents.

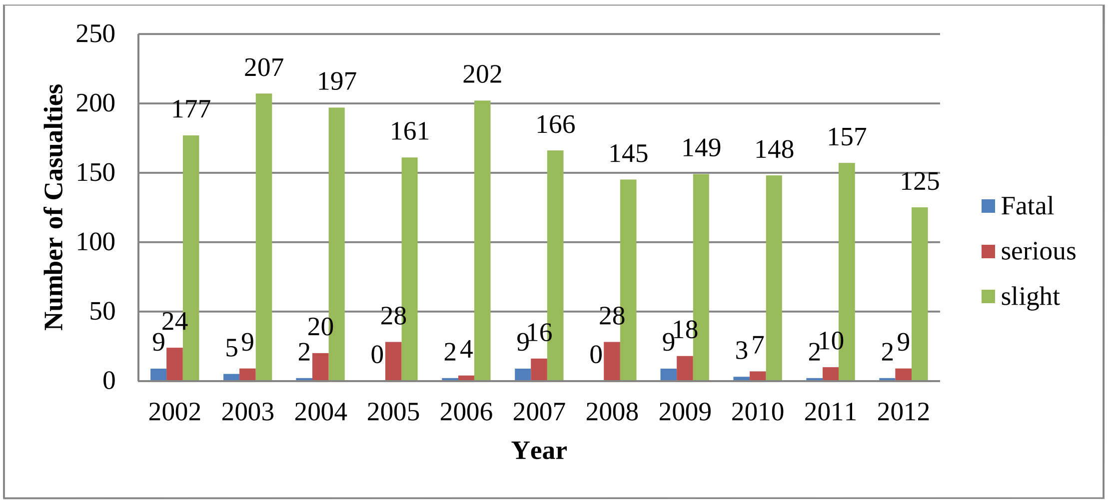


Figure 4-2 Fatal, Serious, and Slight Casualties of Truck Accidents 2002–12

4.2.2 Vehicle Manoeuvre and Vehicle Type

Figure 4-3 shows the various types of manoeuvres undertaken by different types of vehicle during the accidents. The most common manoeuvre was "going ahead over", which includes 41% of vehicles, followed by waiting to go ahead and slowing or stopping.

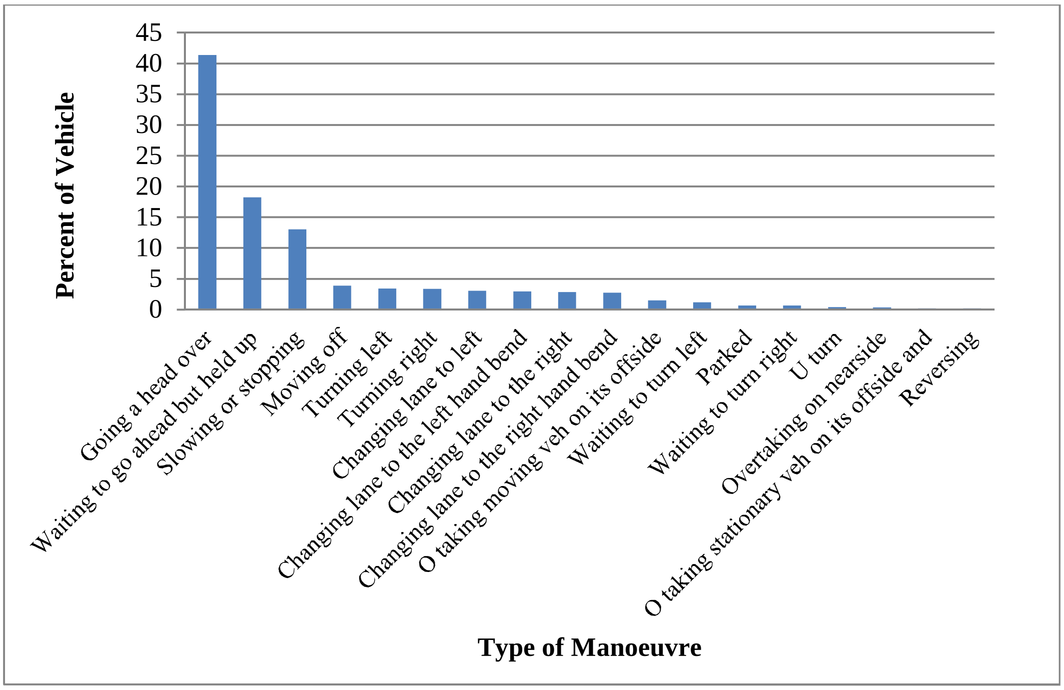


Figure 4-3 Percent of Vehicles by Total Accident Movement Type, 2002–12

It was found that 86% of the vehicle accidents occurred without skidding, jack-knifing, or overturning, while 11% of the vehicles skidded, 1% of the vehicles both skidded and overturned, and 2% of the vehicles overturned. However, of the 3,289 vehicles involved in truck accidents, 3% of the vehicles were overturned, 0.61% jack-knifed, 0.01% overturned and skidded, and only one vehicle overturned and jack-knifed. The DFT (2014) has reported the statistics for accidents involving HGVs, which showed that 9% skidded, 1% jack-knifed, and 4% overturned, which is close to the above results. Rollover and jack-knife accidents commonly occur in truck accidents, as stated by Kennedy (2007), who notes that these accidents mainly occur because of extreme speed or because of harsh braking. The geometry of a roundabout is highly related to these types of accidents: as stated by Arndt (1991), a high ICD can leave trucks unbalanced. Kemp et al. (1978) related truck-accident rollovers and jack-knifes to road surface friction and the lateral acceleration of HGVs. And Ruhl and Dooley-Owen (2012) stated that brake efficiency leads trucks to record jackknifing and swing-out accidents.

Regarding the types of vehicle, 26.6% of accidents include trucks, with the other 73.4% being all other types of vehicle. Maycock and Hall (1983) showed that 6 to 8% of accidents included trucks. Harper and Dunn (2003) record that 6% of accidents involved trucks across 100 roundabouts in New Zealand, and Kennedy (2007) states that 9.3% of accidents included trucks at UK roundabouts. It is clear that the percentage of trucks involved in accidents differs from one study to another, depending on the study year, locations, and study sample, and that the number of trucks included in accidents from one year to another varies.

4.2.3 Accidents by Months of the Year

Figure 4-4 shows the number of casualties from 2002 to 2012 by months of the year. From January to May the number of casualties slightly increases, and then there is a decrease from 703 in May to 670 in June. The selected locations experience the highest number of casualties in May and July, however, while January is the lowest numbers of casualties. In Maycock and Hall (1984), October and April are reported as having the highest and lowest casualty numbers, respectively, while in Kennedy (2007), the highest and lowest numbers are found in November and April, respectively, (see Table 2-6). Probably the highest peak in summer is due to higher traffic volumes as (DFT, 2015) have shown that highest traffic volume including all vehicles is in August and lowest is in January.

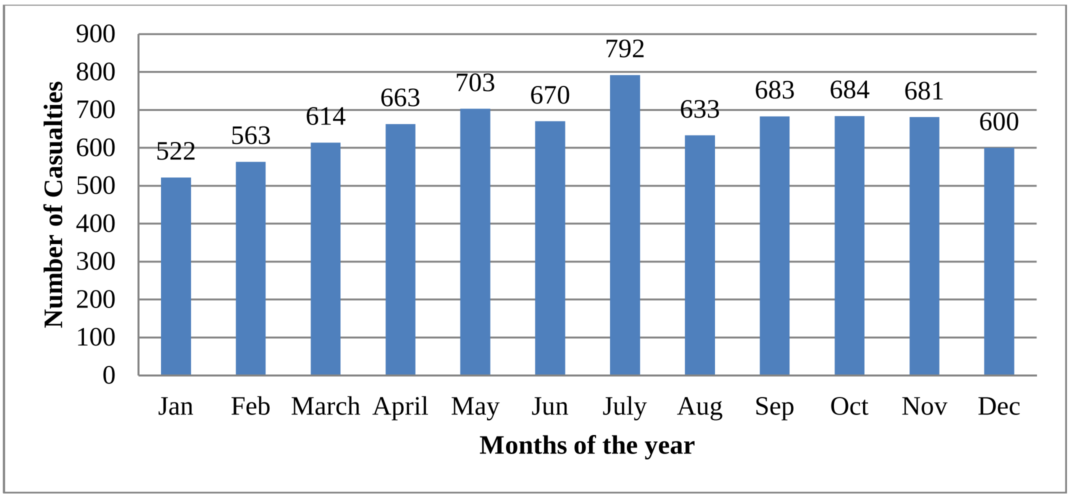


Figure 4-4 Total Accident Rate by Month, 2002-12

Figure 4-5 illustrates the number of casualties in accidents involving trucks by months of the year from 2002 to 2012. From January to February there is a slight increase in the numbers of casualties, but the trend then reverses in March. From then there is a fluctuation in the number of casualties until July which shows the highest number of casualties during the year:

the same as for casualties arising across all accidents. A large decrease in the number of casualties was recorded in August, followed by a further fluctuation in the number of casualties until December. The selected locations experienced the highest number of casualties in July and October, while January was found to be the month with the lowest recorded number of casualties, again reflecting the pattern found when examining all accidents. Note that (DFT, 2015) showed that August is the month associated with the lowest number of HGVs, and traffic peak flow shown in Autumn months, so this might be a reason for having lower number of casualties involving trucks in August and higher in October and November.

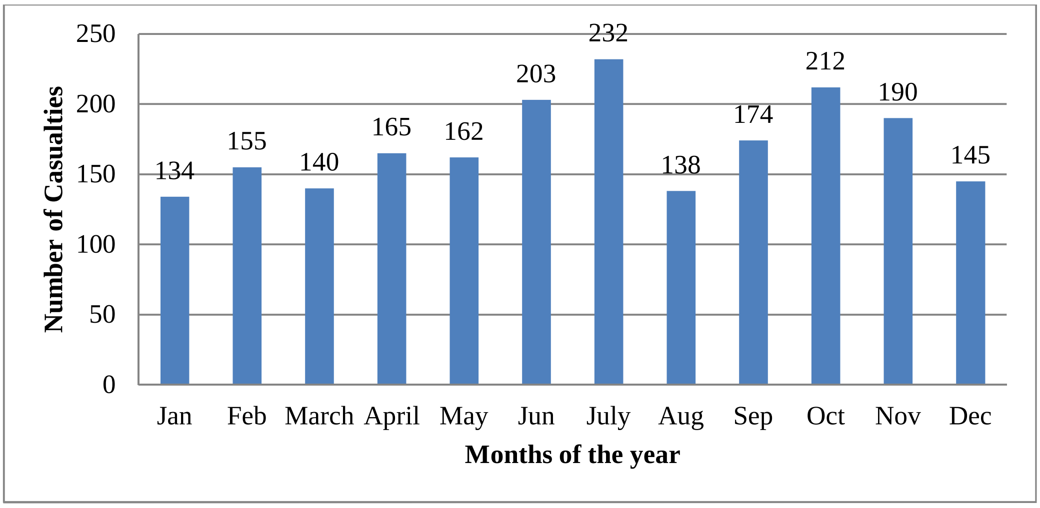


Figure 4-5 Truck Accident Rate by Month, 2002-12

4.2.4 Day of the Week

Figures 4-6 and 4-7 show the injury severity arising from all accidents and truck accidents, respectively, for each day of the week. In total, the highest number of casualties involved across all accidents and only truck accidents is recorded on Friday. Thursday shows the highest number of fatalities in both categories. Overall, Sunday shows the lowest casualty numbers, followed by Saturday, but the most serious injury outcomes for overall accidents combined occurred on Saturday, while Wednesday shows the most serious injury outcomes for accidents involving trucks. These results are broadly in line with the previous studies of Maycock and Hall (1984) and Kennedy (2007). Both studies recorded Friday and Sunday as the highest and lowest days of the week, respectively, for accident casualties. Note that (DFT, 2015) illustrates that in 2014 for all and for HGVs during the weekend traffic volume is particularly lower relative to weekday, which is probably is the reason for having lower number of casualties in weekends relative to weekdays.

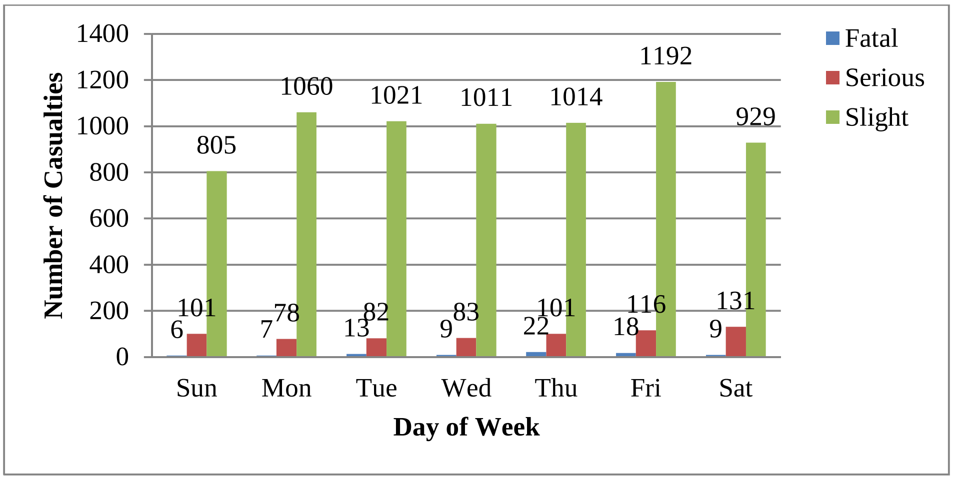


Figure 4-6 Casualties by Day of the Week, 2002-12

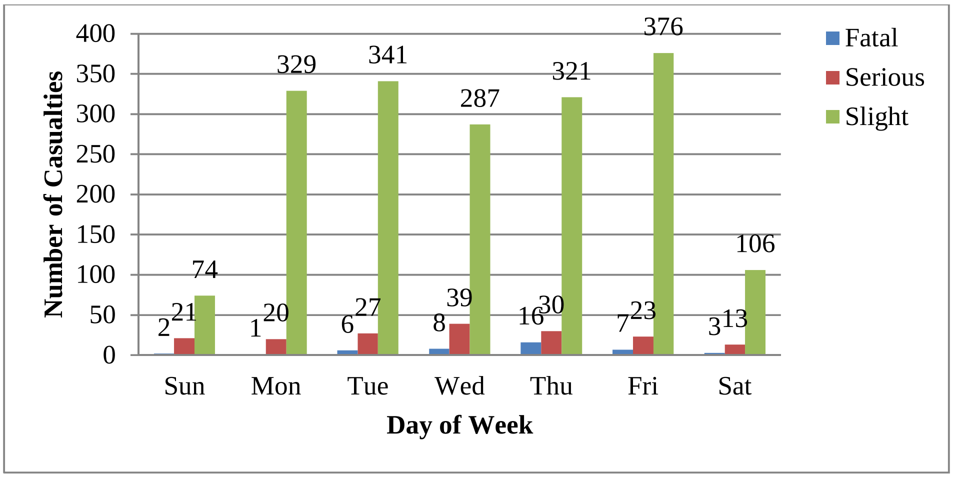


Figure 4-7 Truck Casualties by Day of the Week, 2002-12

4.2.5 Time of Day

Figure 4-8 shows casualty records for all accidents by time of day. The morning peak goes from 6 to 9am with the highest numbers at 8am, after which there is a fluctuation in the number of casualties until 4pm, then the evening peak which runs from then on until 6pm, with the highest casualty numbers recorded at 5pm. When examining all accidents, the highest number of casualties was recorded during the evening peak, which is in line with Maycock and Hall (1984) and Kennedy (2007). Figure 4-9 shows casualty records for truck related accidents according to the time of day. The morning peak again runs from 6 to 9am and, as with total accidents, 8am is the highest of these. However, the pattern of the number of casualties is then dissimilar, as there is a clear peak from 12pm to 2pm which sees the highest number of casualties. After 5pm the number of casualties rapidly decreases. Across the hours of the day there are differences in the occurrence rates of accidents, and this is probably due to the changes in the amount of traffic (i.e., traffic congestion), the speed of vehicles, and the other factors that are illustrated in this chapter which all influence accident occurrences; while the time of day is not included in this study, it is illustrated here to examine the general characteristics of total and truck accidents during different times of day. Note that (DFT, 2015) illustrates that during the morning peak (7 to 9) and the evening peak (4 to 6) the amount of traffic is double of the average level and this is the probable reason of the trends with respect to time of the day.

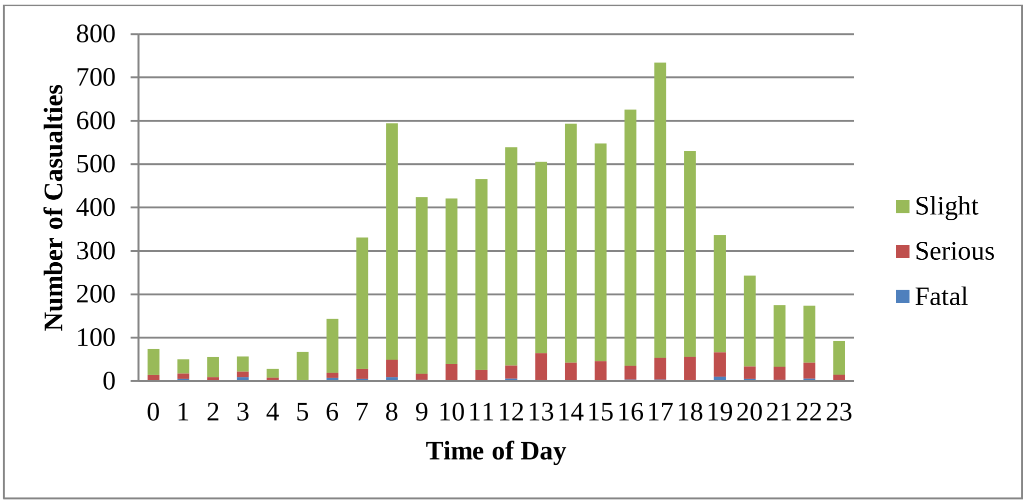


Figure 4-8 Casualties by Hour, 2002-12

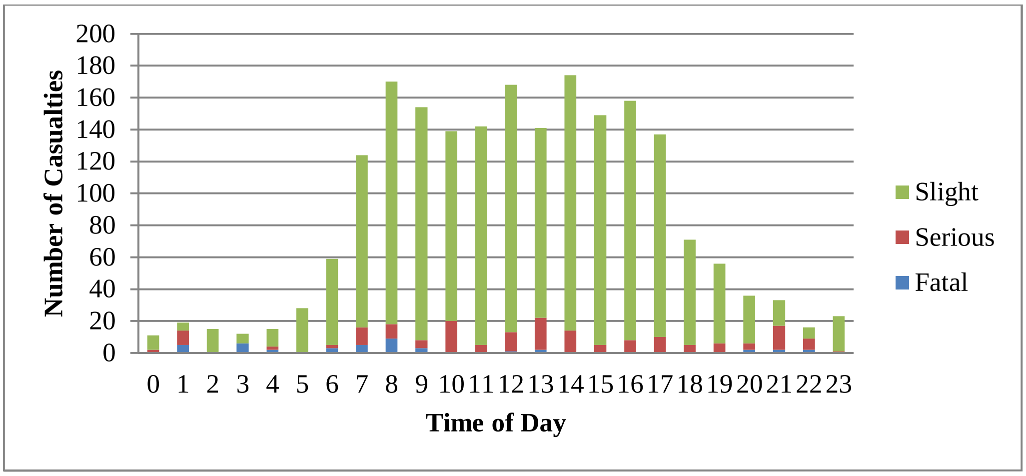


Figure 4-9 Truck Casualties by Hour, 2002-12

4.2.6 Road Surface Condition

Figure 4-10 indicates the types of casualties by road surface condition. In the selected locations, 70% of the fatalities, serious, and slight injuries occurred on dry road surfaces and 30% occurred on wet roads. However, the fatality percentage in wet surface conditions is higher than the fatality percentage in dry surface conditions, as indicated in Table 4-3.

Figure 4-11 indicates the type of casualties by road surface condition for truck accidents. In the selected locations, 72% of the fatalities, serious, and slight injuries occurred on dry road surfaces and 28% occurred on wet roads, which is very close to the proportions of casualties across all accidents; in addition this result is in line with the DFT (2014) which has found that on motorways 67% of accidents occurred on dry surfaces with 33% on wet road surface, although there is again a higher rate of fatalities in wet surface conditions compared to dry surface conditions. Further study would be required to identify the traffic flow in weather that is generally wet compared to those in weather that is dry, so as to conclude more strongly whether or not (and to what degree) wet surface accidents are more severe than dry. In addition, the percentage of people killed in truck accidents is higher than the percentage of people killed in all accidents (2.44% compared to 1.25%). And DFT (2014) reported that on motorways, 1.9% of fatalities were recorded in wet surface conditions with 1.8% in dry surface conditions.

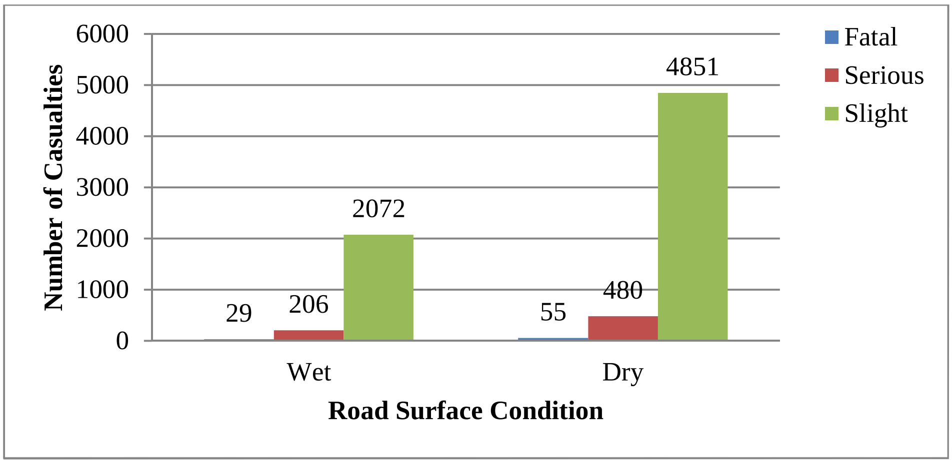


Figure 4-10 Casualties by Road Surface Condition, 2002–12

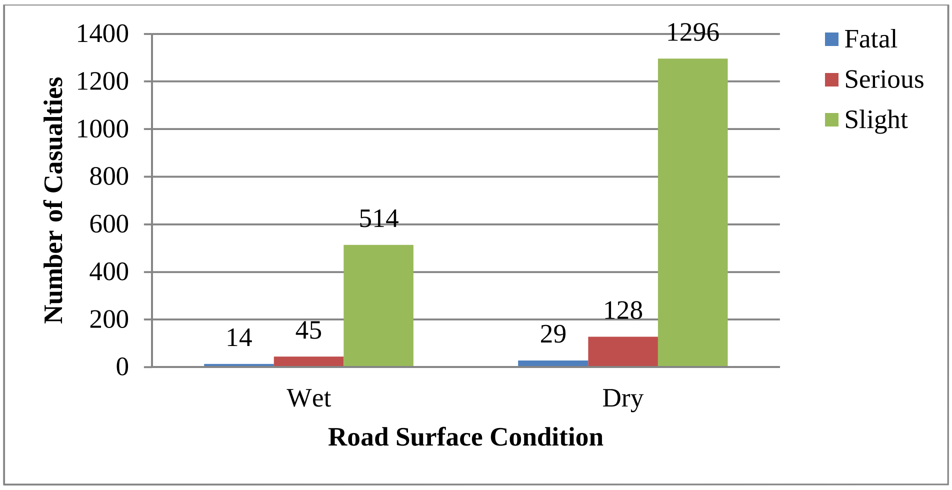


Figure 4-11 Casualties in Truck Accidents by Road Surface Condition, 2002–12

Table 4-3 Casualty and Fatality Percentages During Wet and Dry Surface Conditions

Type of casualty	Total accident		Truck accident	
	Wet	Dry	Wet	Dry
Casualty proportion	30%	70%	72%	28%
Fatality proportion	1.26%	1.02%	2.44%	2%

4.2.7 Light Conditions

According to the STATS19 form, street lighting during the night is divided between known and unknown classifications. So for this analysis, the night data presented includes a collective sum of street lighting of known and unknown classifications. Figures 4-12 and 4-13 show the number of casualties during daylight and night time for total and truck accidents, and Table 4-4 presents the casualty and fatality proportion for both types of accidents. It is clear that the number of overall injuries occurring during daylight is much greater than in darkness for both truck and total accidents. A study by Harper and Dunn (2003) showed that 25% of accidents occurred at night, which is close to our results, and the DFT (2014) has recorded 70% and 30% of accidents in daylight and night conditions respectively, for motorway-class roads. On the other hand, regarding the severity of the accidents, Table 4-4 illustrates that night hours record higher fatalities compared to daytime, for both total and truck accidents. It is clear that a higher number of fatalities arising from truck accidents occurred during the night time and this is in line with the findings of Martin (2002), who found that accident severity was much worse at night; in addition, the results are in line with the DFT (2014), who found that 1.3% of fatalities are recorded during light hours, with 2.9% during the night on motorway-class roads. However, it is a fact that traffic during the night time is lower than in the daytime, which is why the majority of casualties are recorded during the day, but higher fatality numbers were found to occur during the night, and this percentage was much higher in truck accidents compared to all accidents. In this study the amount of traffic was not available with respect to daytime and night time in order to identify the rate of accidents per number of vehicles in daytime and night time which will probably give an answer to if accidents are more severe during the night time relative to daytime. Therefore, further study required regarding this concept.

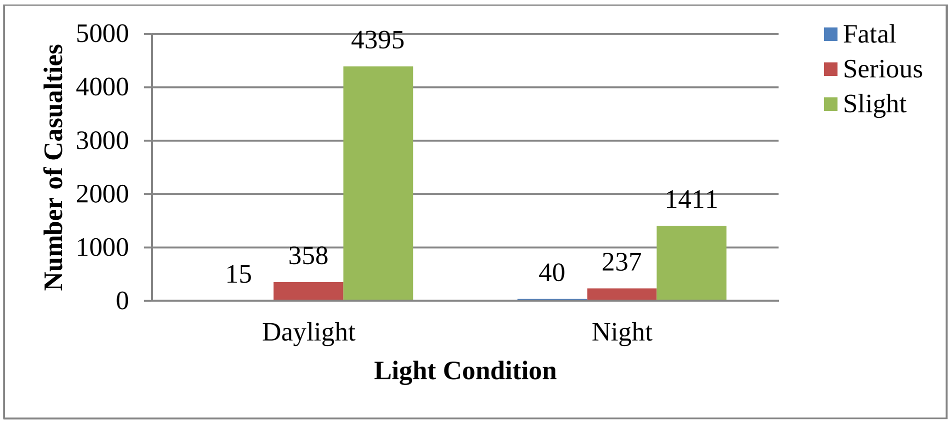


Figure 4-12 Fatalities and Serious Injuries by Light Condition, 2002-12

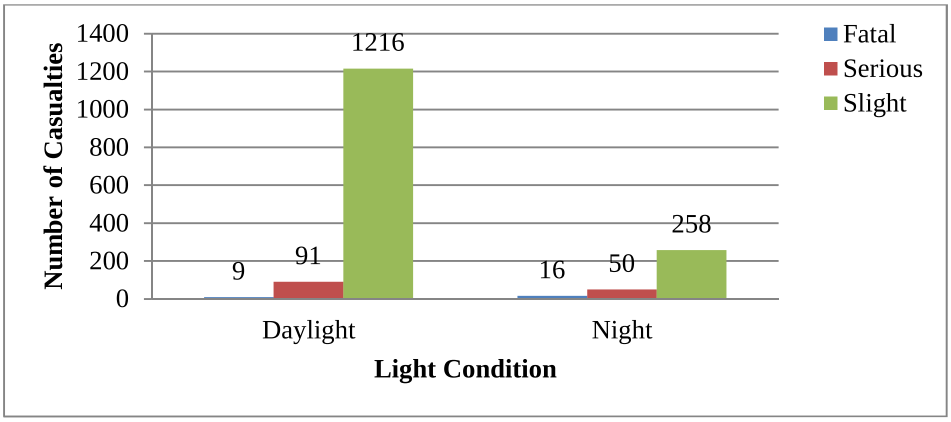


Figure 4-13 Truck Fatalities and Serious Injuries by Light Condition, 2002-12

Table 4-4 Casualty and Fatality percentages during Daylight and Darkness

Type of casualty	Total accident		Truck accident	
	Day light	Night	Day light	Night
Casualty proportion	74%	26%	80%	20%
Fatality proportion	0.31%	2.36%	0.68%	4.9%

4.2.8 Weather Conditions

Figures 4-14 and 4-15 show the casualties by type of injury during different weather conditions. The majority of fatalities, serious, and slight injuries occurred in clear and fine weather, rather than rain, with Table 4-5 indicating the total and truck accident proportion, and that's probably because clear, fine weather is more common. However, the same fatality percentages were recorded during rain and clear weather which means that wet weather is more strongly associated with fatalities even though it is less common. For truck accidents, a higher percentage of fatalities occurred during rainy weather, with a lower proportion of truck accidents during clear weather conditions, including fatalities. The DFT (2014) reported that 79% of accidents occurred during fine weather, with 18% in rain, which is close to the results discussed here, although their findings concerned motorway-class roads; they also reported that the fatality percentage is higher during fine weather (2.1%) than rainy weather (1.3%).

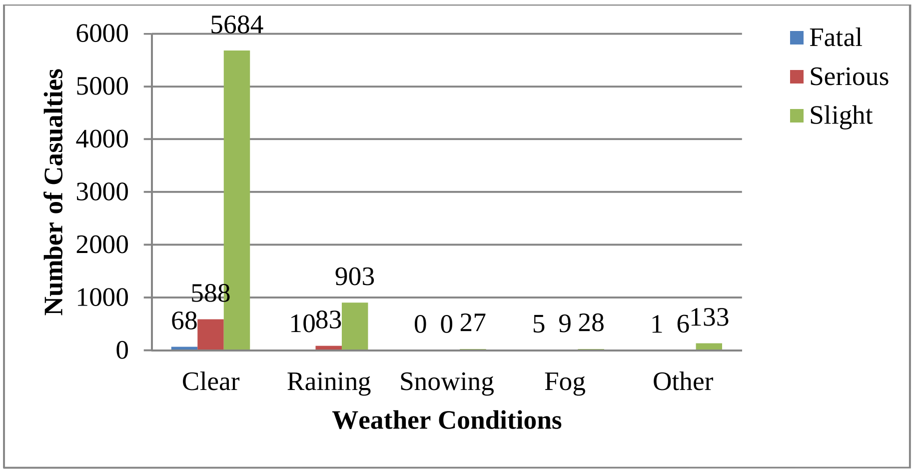


Figure 4-14 Casualties by Weather Condition, 2002–12

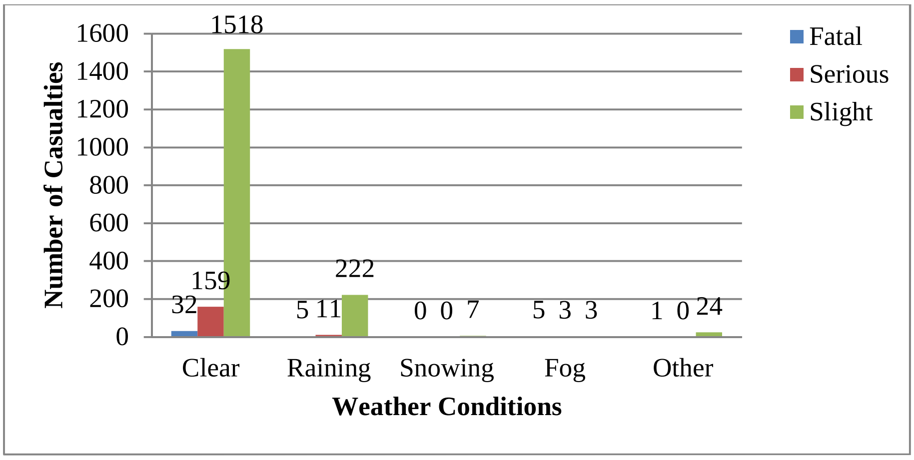


Figure 4-15 Truck Casualties by Weather Condition, 2002–12

Table 4-5 Casualty and Fatality Rates During Clear and Raining Weather Conditions

Type of casualty	Total accident		Truck accident	
	Clear	Raining	Clear	Raining
Casualty proportion	76%	17%	86%	12%
Fatality proportion	1%	1%	1.87%	2.10%

4.2.9 Traffic Control

Traffic control is not included in the STATS19 form, but for the selected locations we have three different types of roundabouts according to traffic control; they are signalised, un-signalised, and partially signalised (see Section 3.3.1 for the description of signalisation). Figure 4-16 illustrates that the majority of casualties occurred in roundabouts that are partially signalised, followed by signalised, with the proportion illustrated in Table 4-6. However, un-signalised roundabouts recorded the highest fatality percentage in comparison to signalised and partially signalised roundabouts (see Table 4-6). The selected locations, as described in Section 3.3.1, consist of 20, 28, and 22 signalised, un-signalised, and partially signalised roundabouts, respectively. While there are higher numbers of un-signalised locations (40%[28]) in the study, and lower recorded casualty numbers, the casualties are of higher severity. 31% of the selected locations are partially signalised, which is close to the percentage of signalised roundabouts (29%), but more casualties were recorded in partially signalised roundabouts. Figure 4-17 shows that the majority of casualties in truck accidents occurred at roundabouts that are partially signalised, followed by accidents at signalised roundabouts. The fatality proportion associated with truck accidents in un-signalised roundabouts is much greater than the fatality proportions at either signalised or partially signalised roundabouts, and is greater than that found for un-signalised total accidents (see Table 4-6). The effect of signalisation on total and truck accidents will be addressed in the model development in Chapter Five.

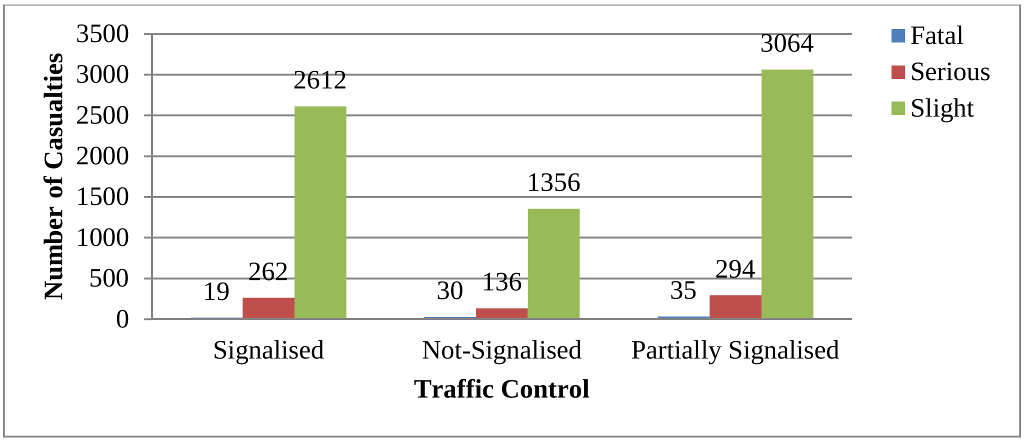


Figure 4-16 Total Casualties by Traffic Control Type, 2002–12

[28] (28/70)*100. Note that 70 roundabouts in total are included in the study

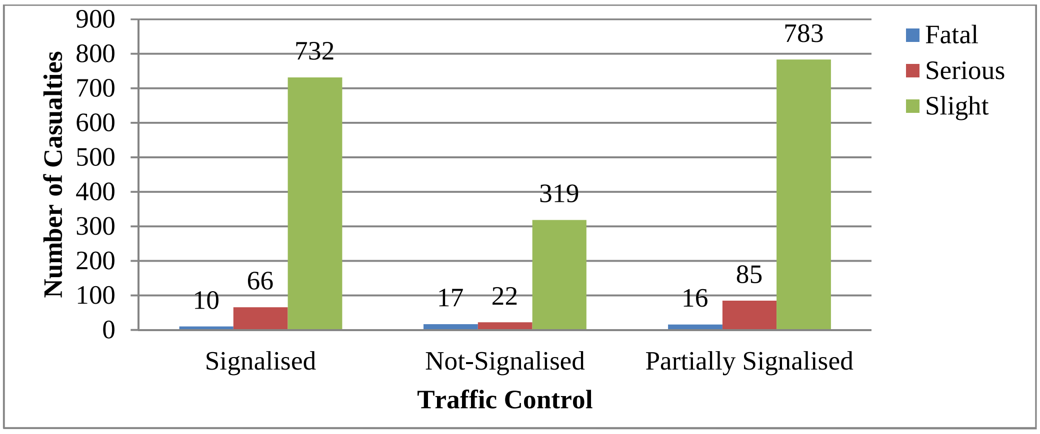


Figure 4-17 Truck Casualties by Traffic Control Type, 2002–12

Table 4-6 Casualty and Fatality Percentages based on Traffic Control

	Total accident			Truck accident		
	Signalised	Un-signalised	Partially signalised	Signalised	Un-signalised	Partially signalised
Casualty proportion %	37	20	43	39.5	17.4	43.1
Fatality proportion %	0.66	1.97	1.03	1.20	4.70	1.80

4.2.10 Number of Arms

Figures 4-18 and 4-19 illustrate the number of casualties based on the number of arms at the selected locations. It was stated in Section 3.3.1 that there are 12 three-arm, 39-four-arm, 12 five-arm, and 7 six-arm roundabouts in the study. It is clear that the highest number of casualties for both total and truck accident categories occurred at four-arm roundabouts, followed by five, six, and three-arms. But when examining the rate of casualties per number of roundabouts (see Figure 4-20) it is clear that for both types of accidents the highest rate of casualties was recorded in five-arm roundabouts followed by six-arm, four-arm, and three-arm roundabouts; and this indicates that as the number of arms increases more casualties are likely to occur per roundabout. Previous studies have found that as the number of arms increases accident rate or numbers increases (Kennedy, 2007; Shadpour, 2012; Kim et al., 2013; and Brude and Larsson, 2000).

Examining the severity of the accidents, Table 4-7 illustrates that six-arm roundabouts show the highest percentage of fatalities, followed by three-arm, and five-arm roundabouts, while the lowest percentage of people were killed was at four-arm roundabouts. Note that all the fatalities in three-arm roundabouts were because of truck accidents (no fatalities were recorded because of other vehicle types). For truck accidents a three-arm roundabout is most likely to result in fatalities compared with other roundabouts. The accident fatality percentage was 8.5% in three-arm roundabout, followed by six-arm and four-arm roundabouts, while five-arm roundabouts recorded the lowest fatality percentage for truck accidents. Kennedy (2007) found that three-arm roundabouts have a low number of accidents but they are more likely to result in more severe accidents as a higher percentage of fatalities and serious injuries were recorded at three-arm roundabouts compared to four-arm roundabouts.

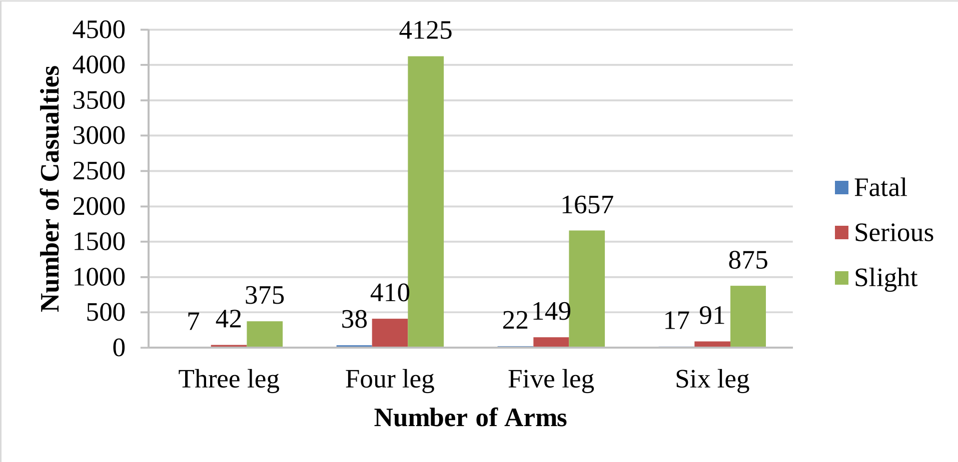


Figure 4-18 Total Casualties by Number of Arms, 2002–12

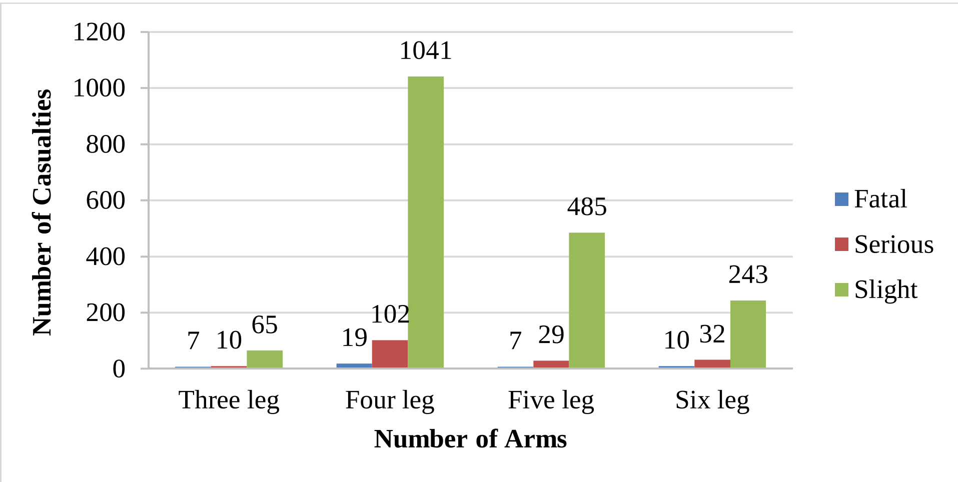


Figure 4-19 Truck Casualties by Number of Arms, 2002–12

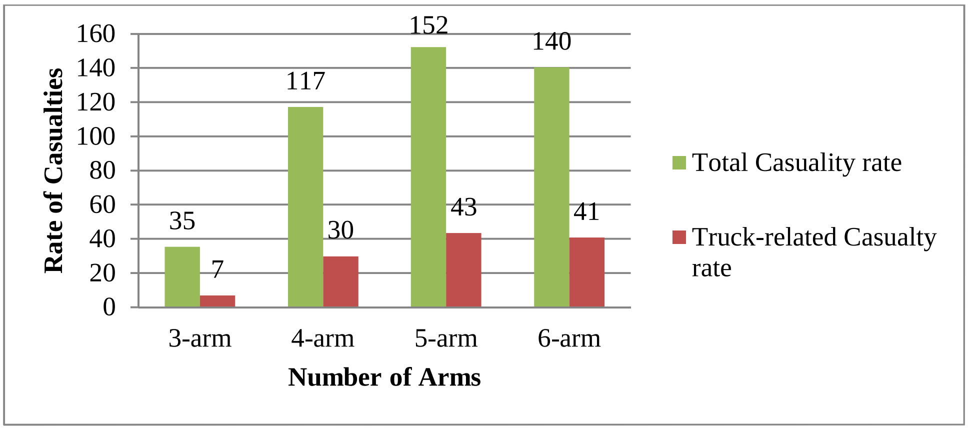


Figure 4-20 Rate of Casualties (Casualties/Roundabouts)

Table 4-7 Fatality Percentage Based on Number of Arms

Number of arms	Fatality proportion in total accidents %	Fatality proportion in truck accidents %
Three-arms	1.65	8.5
Four-arms	0.83	1.6
Five-arms	1.20	1.3
Six-arms	1.73	3.5

4.2.11 Number of Lanes

Figures 4-21 and 4-22 illustrate the casualty trends for all accidents and truck accidents, respectively, by number of lanes. As seen in Table 3-4 there are 31 roundabouts in the study group with three-lanes, and 39 roundabouts with two-lanes. It is clear that higher total and truck casualties are recorded in three-lane roundabouts relative to those with two. In addition, three-lane roundabouts recorded a higher rate[29] of casualties (145 and 32) relative to two-lane roundabouts (85 and 20) for total casualties and truck casualties, respectively. In turn, researchers have found that two-lane roundabouts have a higher number of accidents when compared with single-lane roundabouts (US DOT, 2007; Rodegerdts et al., 2010; Kim et al., 2013; Turner et al., 2006; Šenk and Ambros, 2011; Brude and Larsson, 2000; Harper and Dunn, 2003). Further, Harper and Dunn (2003) found that the percentages of fatalities and serious injury casualties were higher at single-lane roundabouts than at those with two-lanes. In this study no single-lane roundabouts were selected. Figure 4-21 shows that the percentages of fatalities and serious injuries across all accidents for three-lane roundabouts are 11%, and for two-lanes are 8.42%, while for truck casualties, as shown in Figure 4-22, the

[29] Number of casualties/ number of two or three-lane roundabouts

percentage of fatalities and serious injuries for three-lanes are 12.18% and for two-lanes are 7.93%.

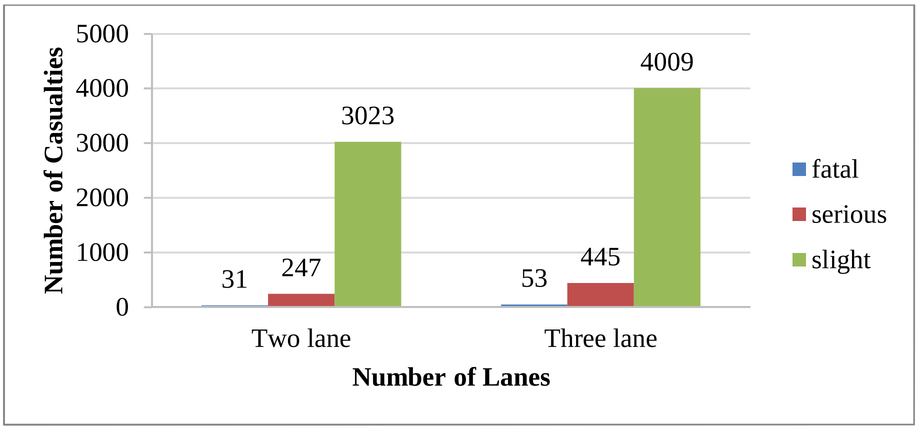


Figure 4-21 Total Casualties by Number of Lanes, 2002–12

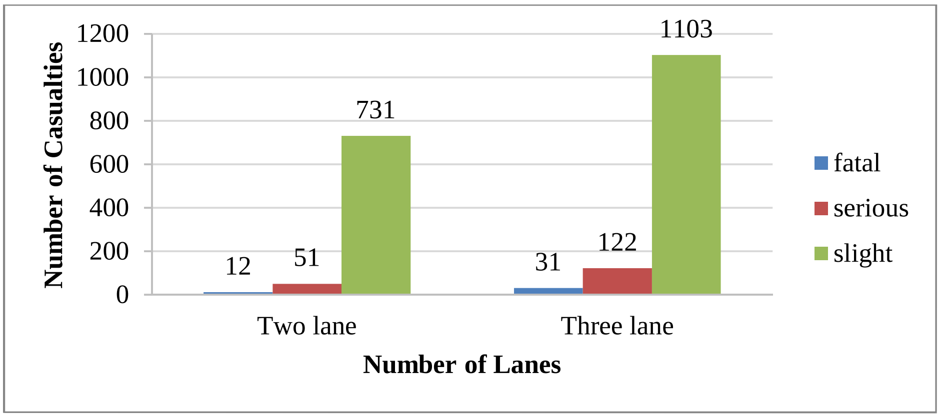


Figure 4-22 Truck Casualties by Number of Lanes, 2002–12

4.2.12 Casualties by Road Class

Regarding the percentage of casualties according to the road type, Table 4-8 illustrates that A-class road entries and exits have the highest percentage of total and truck casualties, followed by motorways, and then B roads. In addition, the highest percentage of vehicles included in total and truck accidents occurred in the entries and exits of A- and B- class roads, relative to M-class roads. Note that the selected locations cover a higher number of A roads (348 entries and exits) than M roads (188 entries and exits), and both exceed the number of B and unclassified roads (26 entries). So it is expected that higher numbers of casualties will be found for A road than for M roads, but when computing the rate per number of road type it is clear that M roads have a similar rate of casualties per M roads compared to A roads. While for truck accidents M road type has more accidents per M roads than A road.

In addition, the percentages of casualties arising from truck and total accidents are the same, as are the percentages of vehicles included in total and truck accidents at A- and M-class roads.

Table 4-8 Percentages of Casualties and Vehicles Involved in Accidents Based on Road Type

Road type[30]	Total Accident			Truck Accident		
	Percent of casualty	Rate (%of casualty /no of roads type)	Percent of vehicles involved	Percent of casualty	Rate (%of casualty /no of roads type)	Percent of vehicles involved
A	65	0.18	64	60	0.17	60
M	34	0.18	35	39	0.21	39

Table 4-9 presents the percentages of fatal, slight, and serious injury casualties with respect to the road class. In Table 4-8 it was seen that A-class roads had the highest proportion of casualties, but the highest percentage of fatality associated with both total and truck accidents was recorded on M-class roads. The percentage of fatalities associated with truck accidents indicates that truck accidents are more severe. The DFT (2014) has reported that motorways see a higher fatality percentage (1.8%) than A road (1.4%).

Table 4-9 Fatal, Serious, and Slight Casualties Based on Road Type

Road type	Total Accident			Truck Accident		
	% of fatal	% of serious	% of slight	% of fatal	% of serious	% of slight
A and B	0.7	8.5	90.8	1.3	8.0	90.7
M	1.8	7.9	90.3	3.3	8.8	88

So motorway approaches have a greater proportion of accidents involving trucks than do A- and B-class approaches and those accidents are more severe.

4.3 Restricted Contributory Factors

This section describes the information on contributory factors for accidents at the selected locations. From 2005, reporting contributory factors had become a part of the STATS19 collection system (DFT, 2012).

Restricted contributory factors for the selected sites for all types of vehicles and for trucks specifically were analysed and a sample of this analysis is illustrated in Table 4-10. The analysis of contributory factors has been carried out in order to assess the responsibility of the driver for an accident as recorded by the police, and in order to see if the results are in line

[30] Note only 1% of casualties were recorded in B and unclassified arms.

with previous contributory factors recorded by the police for all of the UK roundabouts. The results from truck and total accidents illustrate that five of the most frequently reported contributory factors in road accidents were in the category of driver/rider error or reaction, including:

- ‘failed to look properly’ (20.1% and 20.0% for total and truck accidents, respectively)
- ‘failed to judge other person’s path or speed’ (15.8% and 15.4%, for total and truck accidents, respectively)
- ‘following too close’ (8.7% for total accidents and truck accidents)
- ‘poor turn manoeuvre’ (10% for truck accidents and 7% for total accidents)
- ‘sudden braking’ (6.2% and 5.5% for total and truck accidents, respectively)

This result is in line with previous studies, such as the DFT (2014). Their result, however, was for total and truck accidents for all road types: previous literature shows that no analysis of contributory factors has been carried out specifically for roundabouts. In addition, as relates to driver behaviour and its association with accidents, Haque et al. (2016) states that at single-lane roundabouts a distracted condition leads drivers to accidents more like rear-end with the following vehicle because of braking. Qian et al. (2015) stated that at roundabouts older drivers cross roundabouts at higher speed, with less lane changing and at a better gaze looking strategy. Note that, these studies examined the effect on accidents of different variables and manoeuvres from the factors that were reported by the STATS19 report form, and consequently identified different results.

The sample analysis illustrated in Table 4-10 shows the number of vehicles included in accidents based on a number of factors. For each junction the percentage of each factor was identified and the highest were reported. For instance, for J21 on the M1 the total number of vehicles involved in accidents based on the reported contributory factor is 139, so the highest percent in this junction is obtained by dividing each factor code number of vehicles by the total number (for instance 139) multiplied by 100; in this case (i.e. for J21 on the M1) code 405 ‘Failed to look properly’ has the highest percentage of vehicles involved in accidents. The same procedure was carried out for the other 69 junctions and the highest contributory factor for all vehicle accidents is reported is illustrated as in the sample in Table 4-11 (for the other locations see Appendix F, Table F-1). Driver/rider error or reaction is the highest contributory factor recorded at the selected locations (this includes ‘failed to look properly’, ‘failed to judge other person’s path or speed’, ‘following too close’, ‘sudden braking’ and ‘poor turn or manoeuvre’).

Table 4-10 A Sample Analysis of Contributory Factors for Junctions Located on M1 Roundabouts

Roundabout Name	Type of Vehicle	Restricted Contributory Factor Codes and Vehicle Numbers																																												
		101	102	103	107	108	109	301	302	305	306	307	308	401	402	403	404	405	406	408	409	410	501	503	505	509	510	601	602	603	604	605	606	607	702	705	706	707	708	710	802	803	805	808	903	999
J21	all			2	8	1			1			7	22	1	2	8		25	25	5	1	3		6	3			3	8	4				2			1	1								
	HGV				4				1				5		1	3		3	4	2		1		2					1	1				1			1									
J23	all			1							1	2	26			2	1	8	10	4		3	1	1			1	1	7			2								1					1	3
	HGV																	1	4	1			1	1					1																	
J26	all	1		7	1	1		1	1	4	3	6	13	2	3	11	4	28	10	14	1	5				2	1	4	12	1		2			2		1			1	1					2
	HGV			1						1	1		5		2	3	1	3	2			3				1			4	1																
J27	all			5					2	2		5	5	3	3	6	1	23	16	6	2	7	1			2		1	1							2	1			1						1
	HGV											1	1		1		1	6	3		1	2				2																				
J28	all		7	4				1			6	3	50		4	20		100	71	15		6				3	11	12	38	9		2	2	1				7		8						11
	HGV			1									4			4	5	8	11	2		1				1			9	1										2						2
J29	all	1		3			3				2	10	37	1	11	29		115	147	16	5	8	3	1	11	7	4		21	1		3					4	2	2	4	1	3				1
	HGV	1					1					2	6		2	3		15	22	3	3	1			4				3			1								2		1				
J30	all			3					1	1		8	15	3	2	6		41	40	6	3	22	6		13	5				2		1							3	1						1
	HGV			1					1		3	1	5			1		5	8	2	1	7		1															1							
J33	all											5	14	1	4	18		36	43	8	1	6	6		2	1	3	1	11	3	2	3		2				1	2				1			
	HGV												1			3		4	5	1		1		1					2										1							

Table 4-11 Highest Contributory Factor at the Selected M1 Roundabouts

Roundabout	Highest contributory factor	Percentage of accidents reporting this factor
J21 on M1	Failed to look properly	18
J23 on M1	Following too close	35
J26 on M1	Failed to look properly	19
J27 on M1	Failed to look properly	24
J28 on M1	Failed to look properly	26
J29 on M1	Failed to judge other person's path or speed	32
J30 on M1	Failed to look properly	22
J33 on M1	Failed to judge other person's path or speed	25

4.4 Characterising the Type of Accidents by Distance

The number of accidents that occurred in each arm of the selected roundabouts differed from one location to another. The accidents occurred at different distances from the give way line (approach entry). In order to characterise the type of accidents by distance, the data were divided into three groups, one within the circulatory area of the roundabout, one on the approach within 100m of the entry, and the other more than 100m from the entry (up to a maximum of 350m from the roundabout centre), so as to understand how far the accident occurred away from the approach's entry line and to compare them with HBIs. As described in Section 3.3.3 these two distances were chosen based on the occurrence of HBIs at approaches to the roundabouts, as it was found that HBIs were clustered within 100m of the entry lines for most of the locations, although some of the HBIs occurred beyond that distance, see Figure 3-9.

It was found that most of the accidents (2,318, or 60%) occurred within the 100m distance, while 284 (7%) accidents occurred at a greater distance from the entry line and 1,234 (32%) accidents were recorded within the roundabouts' circulatory lanes. Some arms of certain junctions have higher numbers of accidents outside the 100m distance relative to other locations, for instance the west and north directions of the J3 on the M27, north of A14/A141, east of J20 on the M5, and west of J2 on the M6. These locations on average see a high number of accidents, for instance J3 on the M27 is a roundabout for which all the approaches are from M roads, J20 on the M5 is a partially signalised five-arm roundabout, the A1/A141 junction is a grade-separated roundabout with a high truck percentage and high AADT, and J2 on the M6 is a six-arm roundabout, one of which comes from the M69. All of these factors increase the traffic volume for these particular roundabouts.

4.5 Characterising Total and Truck Accidents by Traffic Variables

In this section the influence of the main geometric and traffic characteristics on total and truck accidents is illustrated, before building a model which is presented in the next chapter. The aim of this section is to show how total and truck accidents vary around the selected whole roundabouts, the circulatory lanes, and the approaches with respect to each of the individual traffic characteristics based on different geometric layout of the roundabouts. This will help explore how AADT and percentage of truck traffic influence accident numbers due to these geometric characteristics, which help identify if there are similar or different trends in each of the selected geometric categories in order to take into account their effects in the model development.

4.5.1 Whole Roundabout Total and Truck Accidents

Accident data for the whole roundabout includes all accidents occurring at the approaches and in the circulatory lanes throughout the 11-year period. Table 4-12 illustrates the number and rates of truck and total accidents based on the geometric factors that are considered in this thesis.

Table 4-12 Accident Numbers According to Different Geometric Factors for Whole Roundabouts (Entry and Circulatory)

Factor	Factor category	Number in factor category	Total accident		Truck accident	
			No.	Rate (total accident no. per junction)	No.	Rate (truck accident no. per junction)
Number of arms	Three-arms	12	224	18.7	31	2.6
	Four-arms	39	2312	59.3	540	13.8
	Five-arms	12	1123	93.6	289	24.1
	Six-arms	7	575	82.1	127	18.1
Number of lanes	Two-lane	39	1829	46.9	414	10.6
	Three-lane	31	2405	77.6	573	18.5
Signalisation	Signalised	20	1572	78.6	378	18.9
	Un-signalised	28	798	28.5	138	4.9
	Partially signalised	22	1864	84.7	471	21.4
Type of grade	Grade-separated	51	3665	71.9	884	17.3
	At-grade	19	569	29.9	103	5.4

The rate illustrated in Table 4-12 is the number of accidents per factor category. Based on the number of arms, five-arm roundabouts showed the highest rate of total and truck accidents followed by six-arm roundabouts and four-arm roundabouts. Three-arm roundabouts show the lowest number and rate of accidents (and are all located at at-grade locations). This indicates that as the number of arms increases accidents increase as found by Kennedy (2007), Brude and Larsson (2000), Kim et al. (2013), and Shadpour (2012). Roundabouts with three-lanes as a whole have a higher number and rate of truck and total accidents relative to two-lane roundabouts. Lower numbers and rates of truck and total accidents were recorded in un-signalised roundabouts, followed by signalised and partially signalised roundabouts. In addition, higher numbers and rates of total and truck accidents were recorded in grade-separated roundabouts relative to at-grade roundabouts. Higher numbers of grade-separated roundabouts were selected in this study, but the higher numbers of accidents at these roundabouts may be because of high traffic levels and different geometric designs relative to at-grade roundabouts (more details about the effect of these factors is illustrated in the model development in Chapter Five).

For the selected locations after the data have been filtered and identified (see Section 3.3) then all the geometric and traffic data in addition to accident numbers were entered into an Excel sheet then different sheets were produced separately including accident and traffic data (AADT, and percentage of truck traffic) based on number of arms, number of lanes, signalisation and type of grade. Using SPSS, the correlation between total and truck accidents and AADT and truck traffic percentages was investigated (i.e. AADT and percentage of truck traffic were used as independent variables) with respect to lane numbers, arm numbers, signalisation, and type of grade (see Section 3.4 for the detail of the regression analysis). Table 4-13 illustrates the ANOVA results for total and truck accidents, with AADT, based on the number of arms, the number of lanes, traffic control, and the type of grade (see Appendix G, for the detailed Figures). Note that the outliers identified and discussed in this section were found using visual inspection and they were included in the models presented in the next chapter.

Generally speaking, in two-lane, and in un-signalised roundabouts there is a strong linear relationship between total and truck accidents and AADT. And five arm roundabouts showed a strong linear relationship between total accidents and AADT. Note that five-arm roundabouts constitute the highest rate of accidents (see Figure 4-20) meaning that traffic volume has a significant influence on total accidents in five-arm roundabouts.

Table 4-13 ANOVA Results for Total and Truck Accidents with AADT Based on Different Roundabout Geometric Factors for Whole Roundabouts

Roundabout category/factor	Total Accident with AADT			Truck Accident with AADT		
	R^2	*p*-value	Sig	R^2	*p*-value	Sig
Three-arm	0.06	0.449	no	0.0006	0.94	no
Four-arm	0.15	0.016	yes	0.18	0.006	yes
Five-arm	0.41	0.025	yes	0.16	0.205	no
Six-arm	0.13	0.419	no	0.07	0.568	no
Two-lane	0.52	0.000	yes	0.43	0.000	yes
Three-lane	0.11	0.062	yes	0.096	0.089	yes
Signalised	0.05	0.344	no	0.05	0.338	no
Un-signalised	0.43	0	yes	0.34	0.001	yes
Partially signalised	0.22	0.027	yes	0.16	0.062	yes
Grade-separated	0.22	0.001	yes	0.17	0.002	yes
At -grade	0.36	0.006	yes	0.27	0.021	yes

Table 4-14 illustrates the ANOVA results for total and truck accidents, with percentage of truck traffic, based on the number of arms, the number of lanes, traffic control, and the type of grade.

Table 4-14 ANOVA Results for Total and Truck Accidents with Percentage of Truck Traffic Based on Different Roundabout Geometric Factors for Whole Roundabouts

Factor	Total accident with truck%			Truck accident with truck%		
	R^2	*p*-value	Sig	R^2	*p*-value	Sig
Three-arm	0.11	0.295	no	0.05	0.474	no
Four-arm	0.09	0.02	yes	0.24	0.001	yes
Five-arm	0.14	0.358	no	0.24	0.109	yes
Six-arm	0.53	0.065	yes	0.48	0.082	yes
Two-lane	0.002	0.786	no	0.04	0.248	no
Three-lane	0.23	0.003	yes	0.41	0.000	yes
Signalised	0.39	0.004	yes	0.6	0.000	yes
Un-signalised	$5*10^{-8}$	0.999	no	0.0011	0.868	no
Partially signalised	0.16	0.062	yes	0.33	0.005	yes
Grade-separated	0.23	0.000	yes	0.37	0.000	yes
At -grade	0.014	0.629	no	0.024	0.528	no

When total and truck accidents related to percentage of truck traffic at six-arm roundabouts, three-lane roundabouts, and at signalised roundabouts, it was found that there is a strong linear relationship between accidents and percentage of truck traffic, indicating that truck % has a high impact on both accident types in these types of roundabouts. Tables 4-13 and 4-14 indicate that no statistically significant linear effect of variation in AADT on the variability of total and truck accidents was detected for three-arm and six-arm roundabouts, the probable reason is that small numbers of three-arm and six-arm roundabouts were included in this study. The outliers in Figure 4-23 were identified by visual inspection and they were included in the models developed in the next chapter. These outliers shows that a higher number of total and truck accidents with lower AADT. One of the points is J29 on the M1, which is a six-arm roundabout and recorded a high number of total accidents (152) and truck accidents (54) at approaches and within the circulatory lanes: this junction is partially signalised and has a high ICD (280m). The lower outlier in the six-arm roundabouts examined in Figure 4-23 recorded higher total accidents (55) with lower AADT. This roundabout is J4 on the M53, and has a high average entry width (9.8 m), circulatory width (13m), and high ICD (224m) and is signalised. The three-arm outlier at which a high total accident number was recorded (62) with lower AADT is the at-grade roundabout at the A1237/A64 junction which is signalised and has a high ICD (133m) compared to the other three-arm roundabouts. The majority of three-arm roundabouts recorded lower numbers of truck accidents at the different rates of AADT. This relationship in three-arm roundabouts was found to be statistically insignificant for total and truck accidents with respect to the percentage of truck traffic.

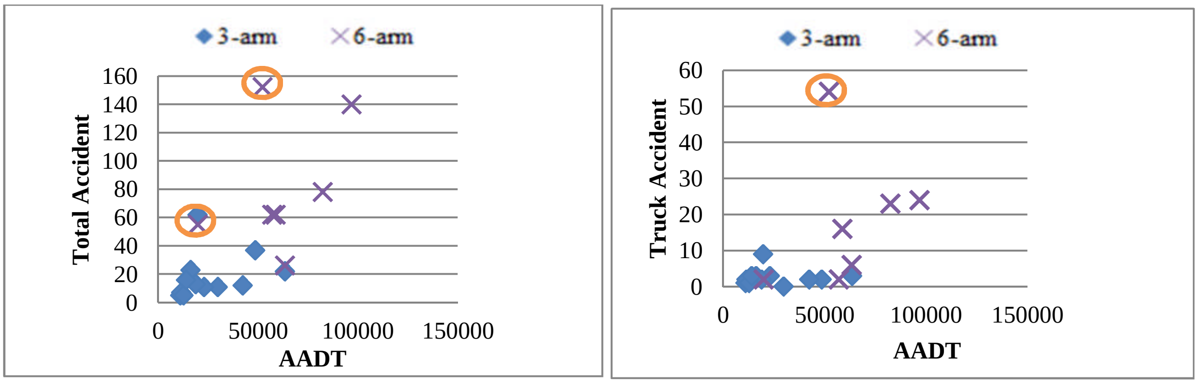


Figure 4-23 Correlation Between Total and Truck Accidents with AADT in Three and Six-Arm Roundabouts

Comparing 4-arm with 6-arm roundabouts the results in Table 4-14 indicate that total accident with truck traffic percentage for four-arm roundabout is statistically significant, but with R^2 of 0.09, probably from a practical point of view it is negligible, thus percentage of truck traffic increases accidents but only by a small amount. Whereas, at 6-arm roundabouts it seems increasing truck percentage has a large effect.

The number of lanes is usually related to the amount of traffic in the road network; for congested roads for instance, or motorways, probably a higher number of lanes are required, and in this study different types of roads were selected with different traffic levels. The variability in total and truck accidents in two-lane roundabouts was found to be highly related to the variation in AADT, with 52% and 43% variation for total and truck accidents respectively, and was found to be significant at p-value<0.001. For three-lane roundabouts these rates declined to 11% and 9.6% variation, respectively, with respect to the variation of AADT. When total and truck accidents were related to the percentage of truck traffic at two-lane roundabouts, no statistical linear relationship was found. However, in three-lane roundabouts, as Table 4-14 indicates, total and truck accidents change linearly with the percentage of truck traffic in higher rates than AADT.

39 of the selected roundabouts have two-lanes, 24 of them are grade-separated roundabouts which have a higher number of AADT than the other 15 two-lane roundabouts, and the rate of truck traffic varies from less than 5% to 13% (see Figure 4-24). The outlier locations illustrated in the left of Figure 4-24 have low truck percentages with high numbers of total accidents and they are the A1237/A64, J17 on the M4, J20 on the M5, and J6 on the M54. Other locations generally show high and low number of total accidents when truck percentages increase. The indicated locations illustrated in the right of Figure 4-24 showed higher numbers of truck accidents with higher truck percentages in a broadly linear relationship. These locations are grade-separated locations located on different M-class roads and the majority of them have four-arms. Apart from these locations, the remaining roundabouts show small numbers of accidents involving trucks regardless of truck percentage, which means that probably percentage of truck traffic has no effect on occurrence of these accidents in a linear relationship.

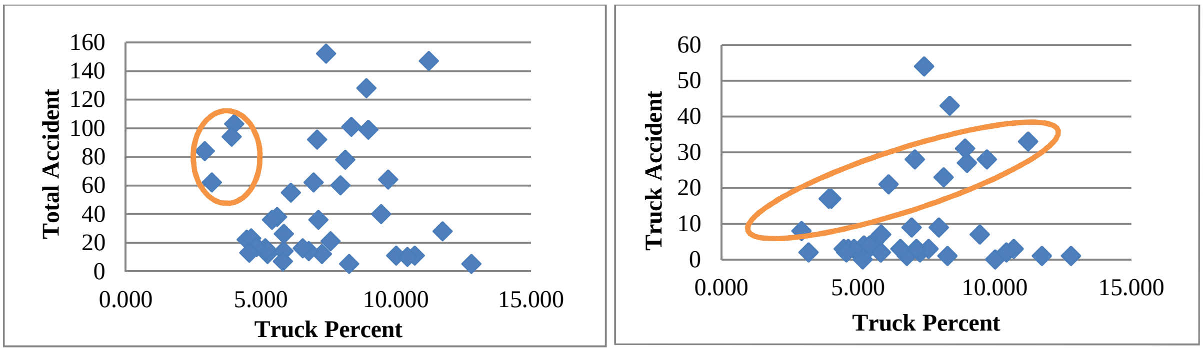


Figure 4-24 Correlation Between Total and Truck Accidents and the Percentage of Truck Traffic in Two-Lane Roundabouts

While signalisation is mainly installed for the control of traffic through the road network, it has its own effect on the occurrence of accidents. As Figures 4-16 and 4-17 illustrate, partially signalised roundabouts have higher numbers of casualties, followed by signalised and un-signalised roundabouts; in addition, although un-signalised roundabouts show a lower number of casualties (20% of causality in 40% of un-signalised roundabouts), a higher percentage of fatalities are recorded at these roundabouts. Accidents are related to traffic characteristics based on signalisation to explore how the signalisation affected the current amount of traffic and accident occurrences. Un-signalised and partially signalised roundabouts show a linear relationship between total and truck accidents with AADT: as in Table 4-13 illustrated that based on R^2 statistically it seems that in un-signalised and partially signalised roundabouts AADT increases have a large effect. Figure G-3 and G-4 (Appendix G) indicates that signalisation installed based on traffic control as un-signalised roundabouts generally have lower level of AADT compared to signalised and partially signalised roundabouts.

However, when examining the relationship between total and truck accidents and the percentage of truck traffic (see Table 4-14), signalised roundabouts statistically showed a significant relationship for total accidents and for truck accidents; in addition, 60% and 33% of the variation in truck accidents can be explained by the variation of truck percentage, in signalised and partially signalised roundabouts, respectively, and practically at signalised and partially signalised roundabouts it seems that increase of percentage of truck traffic has a large effect.

This relationship was found to be insignificant statistically, however, in un-signalised roundabouts, and from a practical point of view R^2 of $5*10^{-8}$ and 0.0011 for both types of accidents, respectively, is considered negligible. The majority of un-signalised roundabouts see truck percentages vary between 5 and 13% (see Figure 4-25), and in general lower numbers of accidents were recorded even when the truck percentage was high, excepting the outlier in the left and right of Figure 4-25 which is J17 on the M4, showing a high number of total accidents (103) and truck accidents (21) with a low percentage of truck traffic. Almost all the other locations have recorded lower numbers of total and truck accidents with different and greater truck percentage levels. This indicates that accidents at un-signalised roundabouts are highly related to AADT relative to truck% (see Table 4-13 and Table 4-14).

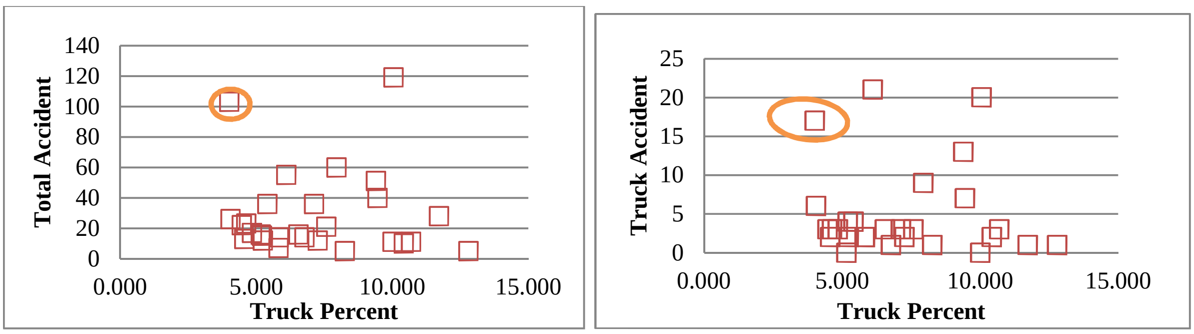


Figure 4-25 Correlation Between Total and Truck Accidents with Percentage of Truck Traffic in Un-Signalised Roundabouts

The majority of grade-separated locations are located on motorway class roads and they see high traffic volumes. All of them have four, five, and six arms, while at at-grade locations the majority of the roundabouts have three arms with lower traffic volume. At grade-separated locations statistically significant linear relationships were found between both total and truck accidents and both percentage of truck traffic and AADT. And at at-grade locations both total and truck accidents were statistically related to AADT, but this relationship was found statistically to be insignificant with percentage of truck traffic. This effect will be illustrated in more detail in Chapter Five. In addition, it is clear from Figure G-7 and G-8 (Appendix G) that at-grade roundabouts show different trends from grade-separated roundabouts with respect to AADT, so it is important to identify the effect of type of grade on accidents using NB models.

For all statistically significant roundabout categories, as illustrated in Table 4-13 and Table 4-14, it can be concluded that at whole roundabouts total accidents are more related to AADT in a positive relationship, compared to truck %, while truck accidents were found to be more related to truck % rather than AADT for the majority of roundabout categories. However, although this is a linear relationship, it is necessary to explore the same relationship using NB models and adding all the geometric and traffic variables; this will be illustrated in Chapter Five.

4.5.2 Characteristics of Total and Truck Accidents Within Circulatory Lanes

A high percentage of total accidents (32%) and truck accidents (36%) are recorded within the circulatory lanes, so the principal aim of this section is to relate total and truck accidents within the circulatory lanes to AADT and the percentage of truck traffic. These will be subdivided with respect to respect to lane numbers, signalisation, and type of grade. This will help explore how AADT and percentage of truck traffic influence accident numbers due to these geometric characteristics, which help identify if there is similar or different trend in each of the selected geometric category in order to take in to account their effect in the model development.

Table 4-15 shows the number and rate of total and truck accidents with respect to the number of lanes, signalisation, and type of grade. Within the circulatory lanes, the rate of total and truck accidents in three-lane roundabouts is much more than the rate of both types of accidents in two-lane roundabouts. As regards traffic control, higher numbers and rate of total and truck accidents happened in signalised and partially signalised circulatory sections, while the rate of total and truck accidents occurring within un-signalised circulatory sections is low.

The rate of total and truck accidents at grade-separated roundabouts is much higher than at-grade roundabouts.

Table 4-15 Accident Numbers According to Different Geometric Factors Within Circulatory Lanes

Factor	Factor category	Number in factor category	Total accident		Truck accident	
			No.	Rate	No.	Rate
Number of lanes	Two-lane	40	524	13.1	109	2.7
	Three-lane	30	710	23.7	194	6.5
Signalisation	Signalised	21	592	28.2	139	6.6
	Un-signalised	30	176	5.9	34	1.1
	Partially signalised	19	466	24.5	130	6.8
Type of grade	Grade-separated	51	1147	22.5	293	5.7
	At-grade	19	87	4.6	10	0.5

Table 4-16 and Table 4-17 illustrate the ANOVA results for the correlation of total and truck accidents with AADT and the percentage of truck traffic, respectively, within the circulatory lanes. It is clear that statistically total accidents are related linearly to AADT in two-lane circulatory roundabouts, and in circulatory lanes that are located in grade-separated roundabouts. This relationship was found to be statistically insignificant in three-lane, signalised, partially signalised and at-grade roundabouts.

Table 4-16 ANOVA Results for Total and Truck Accidents with AADT Based on Different Geometric Factors within Circulatory Lanes

Factor	Total Accident with AADT			Truck Accident with AADT		
	R^2	*p*-value	Sig	R^2	*p*-value	Sig
Two-lane	0.39	0.000	yes	0.25	0.001	yes
Three-lane	0.03	0.325	no	0.04	0.273	no
Signalised	0.03	0.460	no	0.28	0.586	no
Un-signalised	0.04	0.275	no	0.011	0.583	no
Partially signalised	0.11	0.166	no	0.016	0.019	yes
Grade-separated	0.12	0.014	yes	0.10	0.022	yes
At-grade	0.09	0.211	no	0.22	0.041	yes

The single outlier illustrated in Figure 4-26, for three-lane, signalised and grade-separated locations, is the same location which saw a high number of total accidents with a low number of AADT, the A14/A141 junction, in which there is the highest percentage of truck traffic, but where AADT is not high relative to other locations, yet higher numbers of accidents are recorded in the circulatory section of this roundabout (108 accidents). The un-signalised circulatory sections (whether at-grade or not) and circulatory sections that are located in at-grade roundabouts (whether signalised or not) marked on Figure 4-26 (right) and (centre), respectively, showed a different trend from signalised and grade-separated locations. There are 19 at-grade roundabouts, of which 16 were un-signalised within the circulatory system, and this is the probable reason for the appearance of that trend. In addition, these locations recorded lower numbers of accidents with different rates of AADT when compared with grade-separated, signalised, and partially signalised roundabouts.

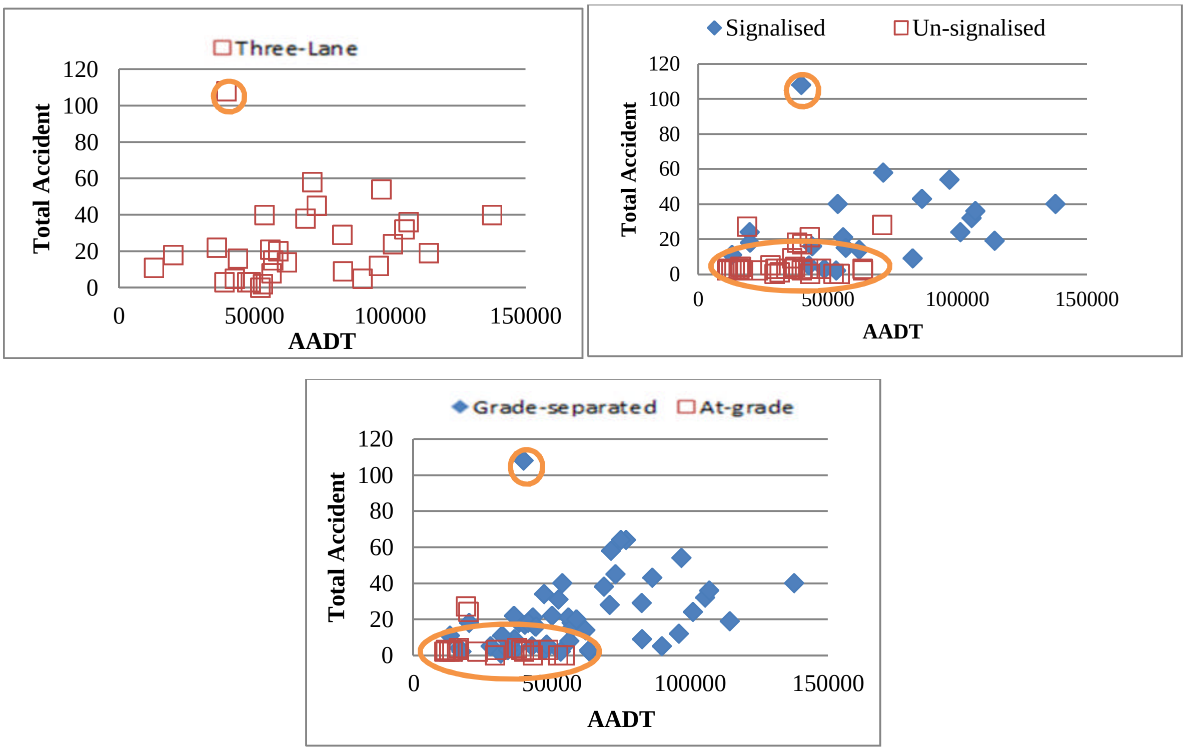


Figure 4-26 Correlation Between Total Accident Figures with AADT in Three-Lane (left), Signalised and Un-Signalised (right), and Grade-Separated and At-Grade (centre) Roundabouts

When relating truck accidents with AADT within the circulatory lanes, Table 4-16 reveals that two-lane, partially signalised, grade-separated and at-grade roundabouts showed a linear relationship between the two. Moreover, three-lane, signalised and un-signalised roundabouts showed that statistically there is no linear correlation between truck accidents and AADT.

Total accidents and AADT, and truck accidents and AADT, in un-signalised roundabouts showed a different trend from other types of signalling (see Figure 4-27). This trend indicates that lower numbers of truck accidents were recorded in un-signalised roundabouts with the same amount of AADT, relative to other traffic controls. Note that there are 30 un-signalised circulatory sections, and 16 of them are located in at-grade roundabouts. The un-signalised trend reveals that the occurrence of total and truck accidents within the circulatory lanes is not related to AADT, but is related to the traffic control type and the type of grade.

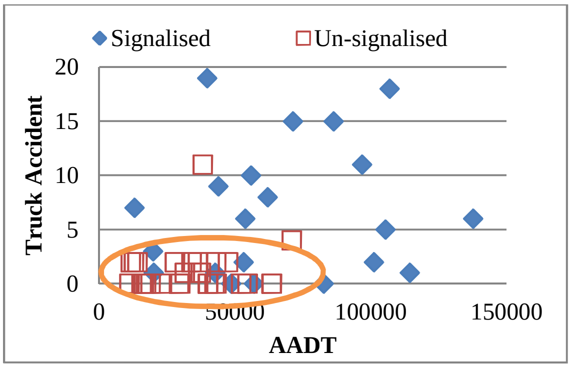


Figure 4-27 Correlation Between Truck Accidents with AADT in Signalised and Un-Signalised Roundabouts

Table 4-17 illustrates that total accident numbers within the circulatory lanes are highly correlated to the percentage of truck traffic in three-lane, signalised, and grade-separated roundabouts, in which 44% and 58% of the variation in total accidents can be explained by the variation of truck traffic, for three-lanes and signalised circulatory lanes, respectively. In addition, partially signalised circulatory sections showed a statistically significant linear relationship between total accidents and the percentage of truck traffic. And R^2 of 0.23 indicates that as truck percentage increases the number of truck accidents increases in partially signalised roundabouts.

Figure 4-28 illustrates the relationship between total accidents and the percentage of truck traffic based on type of grade. According to the ANOVA results, both types of roundabouts showed that the number of accidents is statistically related to the percentage of truck traffic. Grade-separated roundabouts, however, showed a different trend from at-grade roundabouts, and this is because higher rates of total accidents were recorded in the circulatory lanes of grade-separated roundabouts relative to at-grade roundabouts (see Table 4-15). In addition, the majority of at-grade roundabouts have three-arms, and are un-signalised which both have lower numbers and rates of accidents, while grade-separated locations constitute four, five, and six-arm roundabouts, and the majority of them are signalised or partially signalised. As a result, a different trend was identified depending on the type of grade.

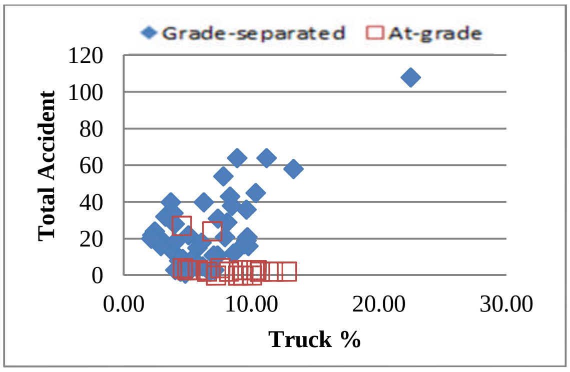


Figure 4-28 Correlation Between Total Accidents and Percentage of Truck Traffic in Grade-Separated and At-Grade Roundabout Circulatory Lanes

Table 4-17 illustrates that in two-lane and un-signalised roundabouts there are no statistically significant linear relationships between total accidents and the percentage of truck traffic. As discussed previously, un-signalised roundabouts have a low rate of total accidents (5.9) within circulatory lanes and this rate is lower than for signalised (28.2) and partially signalised (24.5) circulatory sections with the same level of truck traffic (see Figure 4-29). This indicates that signalisation has an effect on accident occurrence; for this reason it is important that their effect should be considered as a independent variable in modelling process. Further details on the effect of traffic signals are illustrated in Chapter Five.

Table 4-17 ANOVA Results for Total and Truck Accidents with AADT Based on Different Geometric Factors within Circulatory Lanes

Factor	Total accident with truck%			Truck accident with truck%		
	R^2	*p*-value	Sig	R^2	*p*-value	Sig
Two-lane	0.0006	0.883	no	0.008	0.585	no
Three-lane	0.44	0.000	yes	0.27	0.004	yes
Signalised	0.58	0.000	yes	0.52	0.000	yes
Un-signalised	0.077	0.136	no	0.07	0.173	no
Partially signalised	0.23	0.038	yes	0.17	0.078	yes
Grade-separated	0.45	0.000	yes	0.31	0.000	yes
At-grade	0.16	0.089	yes	0.07	0.250	no

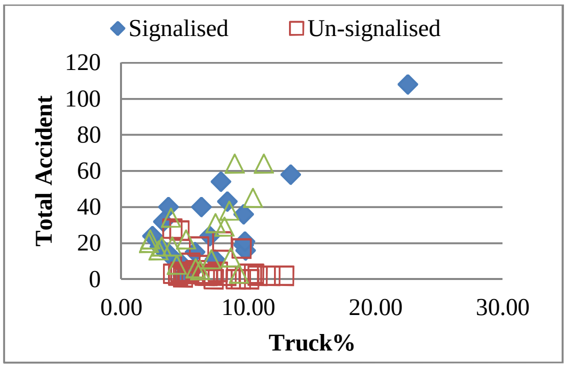


Figure 4-29 Correlation Between Total Accidents and the Percentage of Truck Traffic Based on Traffic Control Within Roundabout Circulatory Lanes

When relating truck accidents to the percentage of truck traffic, three-lane, signalised, and partially signalised circulatory lanes, in addtion to circulatory sections that are located at grade-separated roundabouts, showed a statistically significant relationship (see Table 4-17). And from a practical point of view based on R^2 for each of the significant factor categories, it indicates that as percentage of truck traffic increases the number of truck accidents increases in these locations. Similarly with total accidents, un-signalised circulatory lanes, have very low truck accident numbers and are not statistically related to the percentage of truck traffic. Morover, in two-lane circulatory sections, truck accidents are not related to the truck percentage.

Within the circulatory lanes, it can be concluded that total and truck accidents are highly related to percentage of truck traffic compared to AADT, for the majority of geometric factors. This indicates that truck percentage within the circulatory lanes have high impact on accidents.

4.5.3 Characteristics of Total and Truck Accidents at Approaches

Approaches are analysed separately from the roundabout as a whole and the circulatory lanes. The prediction and analysis of accidents at approaches is necessary for the purpose of design considerations, and in order to make approaches safer for the road users, thereby influencing improvements for the whole roundabout. In this section, total and truck accidents at approaches are related to AADT, truck percentage with respect to the number of lanes, traffic control, and type of grade, in a linear relationship. The aim is to explore how accidents are related to traffic variables at approaches separately, based on different geometric category. This will allow explanation of how accidents are affected by traffic characteristics based in different factor categories and identify if there are similarities or differences between the factor categories a factor so as to know whether consider them in the model development.

Table 4-18 shows the number of total and truck accidents with respect to the number of lanes, traffic control, and type of grade. At approaches, similar to whole and circulatory sections higher rates of total and truck accidents were recorded with three-lanes, relative to two-lanes. However, there is not much difference between the two rates. Regarding signalisation, higher rates of total and truck accidents happened at signalised approaches. On average a higher rate of truck and total accidents was recorded in approaches that are located in grade-separated roundabouts relative to approaches located in at-grade roundabouts.

Table 4-18 Accident Numbers According to Different Geometric Factors at Approaches

Factor	Factor category	Number in factor category	Total accident		Truck accident	
			No.	Rate	No.	Rate
Number of lanes	Two-lane	172	1496	8.7	289	1.7
	Three-lane	112	1176	10.5	259	2.3
Signalisation	Signalised	142	1653	11.6	362	2.5
	Un-signalised	142	1019	7.2	186	1.3
Type of grade	Grade-separated	211	2405	11.4	509	2.4
	At-grade	73	267	3.7	39	0.5

Table 4-19 illustrates the ANOVA results for total and truck accidents with AADT, based on the number of lanes, traffic control, and type of grade. It is clear that a statistical linear relationship was found between total accidents and AADT and also between truck accidents and AADT based on all approach categories, which indicates that as AADT increases at approaches, total and truck accidents also increase.

Table 4-19 ANOVA Results for Total and Truck Accidents with AADT at Roundabout Approaches Based on Different Roundabout Geometric Characteristics

Factor	Total Accident with AADT			Truck Accident with AADT		
	R^2	*p*-value	Sig	R^2	*p*-value	Sig
Two-lane	0.14	0.000	yes	0.06	0.002	yes
Three-lane	0.17	0.000	yes	0.13	0.000	yes
Signalised	0.13	0.000	yes	0.06	0.003	yes
Un-signalised	0.09	0.000	yes	0.06	0.002	yes
Grade-separated	0.11	0.000	yes	0.07	0.000	yes
At-grade	0.11	0.000	yes	0.05	0.061	yes

Table 4-20 illustrates the ANOVA results showing the correlations between total accidents and percentage of truck traffic and also between truck accidents and the percentage of truck traffic. It is clear correlations of both types exist that are statistically significant for all types of approach geometry except for two-lanes.

Table 4-20 ANOVA Results for Total and Truck Accidents with Percentages of Trucks at Roundabout Approaches Based on Different Geometric Characteristics

Factor	Total accident with truck%			Truck accident with truck%		
	R^2	*p*-value	Sig	R^2	*p*-value	Sig
Two-lane	0.008	0.709	no	0.008	0.249	No
Three-lane	0.03	0.074	yes	0.04	0.039	Yes
Signalised	0.06	0.003	yes	0.07	0.002	Yes
Un-signalised	0.03	0.058	yes	0.0008	0.731	No
Grade-separated	0.04	0.004	yes	0.06	0.000	Yes
At-grade	0.01	0.348	yes	0.004	0.597	No

When truck accidents are related to the percentage of truck traffic, as seen in Table 4-20, it can be seen that three-lane approaches, signalised approaches, and approaches that are located in grade-separated roundabouts show a statistically significant linear relationship between the two. However, the value of R^2 is very low so from a practical point of view this effect is considered to be negligible. The observation of two-lane approaches, un-signalised approaches, and approaches that are located in at-grade roundabouts shows that truck accidents and the percentage of truck traffic are not statistically related. Note that Figure 4-30 and Figure 4-31 show that approaches that are located at at-grade roundabouts recorded lower numbers of total and truck accidents relative to the approaches that are located in grade-separated roundabouts, with the same level of AADT and percentage of truck traffic. As for roundabouts as a whole and within circulatory lanes, all at-grade roundabouts show lower numbers of accidents with the same traffic level, because the majority of them have three-arms, are un-signalised, and have a lower ICD, all of which have been found to be related to a lower number of accidents. However, including these variables in a model that suits accident data will supports these findings. In addition, those approaches that are located at grade-separated roundabouts are either located on M or A-class roads, and the traffic level of the approaches that are located on A-class roads is close to the traffic level seen on A-class roads of at-grade roundabouts.

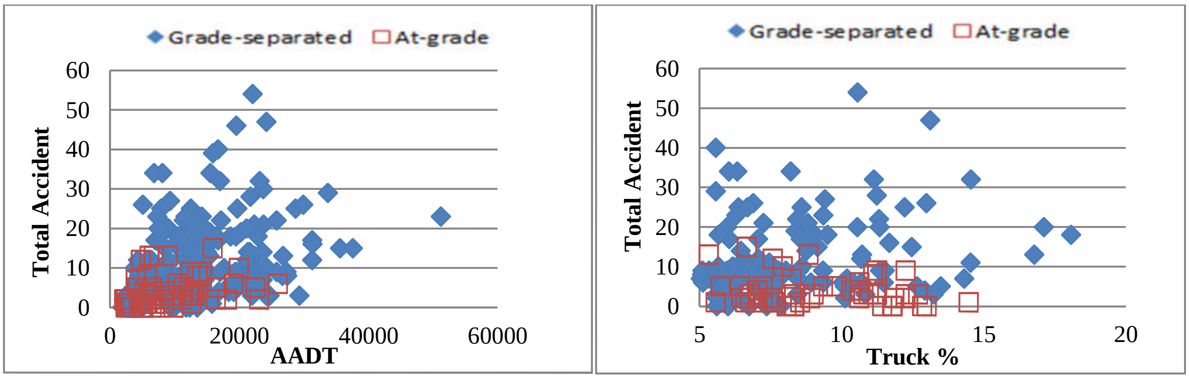


Figure 4-30 Correlation Between Total Accident Numbers, AADT, and Truck Percentage Based on Type of Grade at Approaches

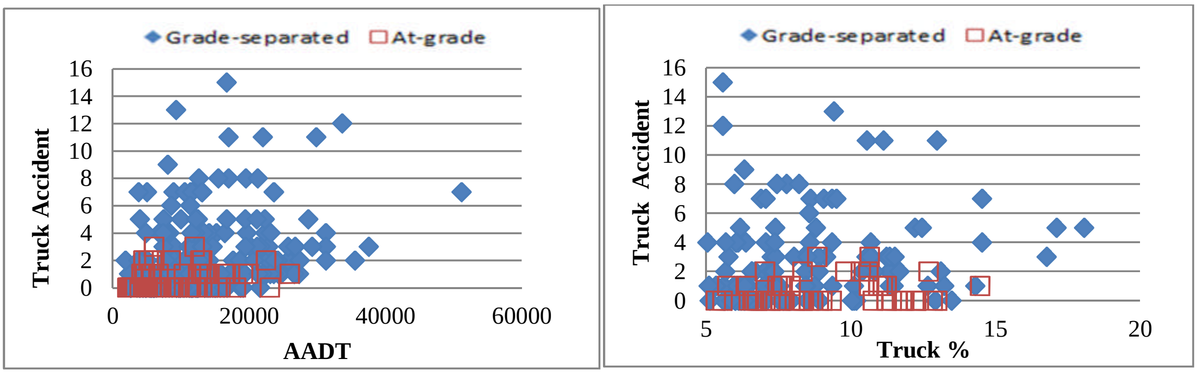


Figure 4-31 Correlation Between Truck Accident Numbers, AADT, and Truck Percentage Based on Type of Grade at Approaches

At approaches, the large variation in AADT and in accidents makes the relationship to practically insignificant because of the low value of R^2. This is probably because there are a number of approaches having zero or one accidents with the same level of traffic compared to other approaches with higher numbers of accidents. This indicates that the relationship between accident numbers and traffic variables is not linear. For this reason, NB regression model will clarify the influence of all geometric and traffic variables together on total and truck accidents, as illustrated in the total and truck accident model development in Chapter Five.

4.6 Summary and Conclusions

In this chapter, total and truck accident trends and contributory factors for accidents were illustrated, using the available accident data for the selected locations through the 11-year period 2002-2012. Total and truck accident casualties were analysed and compared for the selected locations, so as to examine the effects of truck accidents at the selected roundabouts. Accidents occurred in differing road environments and condition circumstances and at different times of day, on different days of the week and in different months of the year. Casualty trends with respect to lane and arm numbers and with regard to traffic control and road class were identified. All these conditions give additional information and initial accident analysis, to assist in building a model based on accident numbers with traffic and geometric parameters.

The number of total and truck casualties from 2002 to 2012 decreased by 37% and 35%, respectively. On average this decrease corresponds to general accident statistics on roads and at intersections (DFT, 2014; Trucks V, 2013; US Department of Transportation, 2014) and for roundabouts (Kennedy, 2007), as discussed in Chapter Two. As such, it can be concluded that general accident trends are falling and that other methods are required to identify locations with high risks of accidents.

Trucks accounted for 26.6% of all vehicles involved in accidents. The fatality rate for truck accidents is much higher than for other vehicles types: 2.1% of truck accidents were fatal, while the figure was 1.07% for accidents involving other vehicle types. This result supports previous findings (DfT, 2014; Trucks V, 2013; US Department of Transportation, 2014; Carstensen et al., 2001; Grygier et al., 2007; Kennedy, 2007). Based on all the trends and fatality rate results illustrated in this chapter, it can be concluded that truck accidents are more dangerous than accidents involving other types of vehicle.

It can be concluded that the highest fatality percentage was recorded in each of the following situations: with a wet surface, at un-signalised roundabouts, at three-arm roundabouts, in rainy weather, at night and at roundabouts serving M-class roads. It can further be seen that this percentage is higher for truck accidents. It can also be concluded that all the trends that are examined and illustrated in this chapter for the selected 70 roundabouts show typical accident characteristics. Studies are needed to confirm the rate of severe accidents is higher, so as to enable firmer conclusions as to whether accidents are more severe at night rather than during the day. In addition, the DfT (2014) has found that more people are killed in wet rather than dry surface conditions, which supports our results, however further study is needed to quantify the hours of wet and dry road conditions.

Driver/rider error or reaction is the most frequently recorded contributory factor at the selected locations. Among such errors, 'failed to look properly' was found to be the highest contributory factor for accidents for all types of vehicle as a whole and trucks on their own. These results support the results presented by the DFT (2014) for the years 2009 to 2013. In these respects, the selected roundabouts have typical accident characteristics.

A 100 m distance from the roundabout entry line was chosen as the limits to the data investigated because the majority of HBIs occur within this distance, in addition DMRB TD 16/07 (2007) use 100 m distance as a standard for designing roundabouts. And it was found that most of the accidents occurred within this distance (60%), with 7% occurring at more than 100m from the entry line, and 32% within the roundabouts' circulatory lanes. And 56%, 36%, and 7% of truck accidents occurred at 100 m, beyond 100 m and within roundabouts circulatory lanes, respectively. Some arms of specific junctions have higher numbers of accidents at greater than 100m distance. These locations on average see a high number of accidents because of higher traffic volume at these roundabouts.

From the ANOVA results it can be concluded that grade-separated roundabouts and at-grade roundabouts show different trends for all the cases. For this reason, it is necessary to build a model for each type of grade based on different traffic and geometric characteristics, and the next chapter illustrates this model. Un-signalised and two-lane roundabouts showed a different trend from three-lane and signalised and partially signalised roundabouts, and it is necessary to examine the effect of these variables on accidents using a NB distribution; more details are illustrated in Chapter Five. In addition, the influence of number of arms has resulted in different trends, so the effect of number of arms will be identified and illustrated in the next chapter.

Chapter 5 Total and Truck Accident Prediction Model

5.1 Overview

The principal aim of this chapter is to identify the factors influencing the number of total and truck accidents that have occurred within the circulatory lanes, the approaches and for the whole selected roundabouts, which is one objective of this study (Characterise the total and truck accidents at a number of roundabouts). Statistical models were used to investigate the relationship between total and truck accidents and traffic and geometric characteristics for the selected roundabouts. The models are (see Section 3.5):

I. Fixed-parameters NB count data models

II. Random-parameters NB count data models

The two models were compared and the best chosen based on statistical tests which will be discussed in the following sections. In addition, as discussed in Chapter 4, grade-separated and at-grade roundabouts were analysed separately for both total and truck accidents and are illustrated in this chapter. The final section summarises each section of the chapter and compares the results with previous studies.

5.2 Correlation between Independent Variables

In order to identify the correlation between independent variables (geometric and traffic) that are used to build the models for total accidents, truck accidents, and HBIs (see Chapter Seven), collinearity tests were carried out, using R^2 and the variation inflation factor (VIF) as an indicator of collinearity (see Section 3.5.3, Eq. (3-10) and (3-11)). Tables 5-1a, 5-1b, and 5-1c illustrate the correlation between all the geometric and traffic variables that are tested to build the models for whole roundabouts, within the circulatory lanes, and at approaches.

As explained in Section 3.5.3, if VIF $\geq$ 5 between two independent variables one of the variables should be excluded from the model, in this case if any $R^2 \geq 0.80$ between any two independent variables one of them should be excluded. This is because collinearity between two variables results in high standard errors and makes the independent variable appear insignificant while it may be significant statistically.

Table 5-1a R^2 and VIF Results of Correlation Between Independent Variables for Whole Roundabout

variable	ICD		Circulatory width		Entry width		Three-arm indicator		Four-arm indicator		Five-arm indicator		Signalised indicator		Un-signalised indicator		Lane number indicator		Type of grade indicator		Truck percentage		ln(AADT)
	R^2	VIF	R^2	VIF	R^2	VIF	R^2	VIF	R^2	VIF	R^2	VIF	R^2	VIF	R^2	VIF	R^2	VIF	R^2	VIF	R^2	VIF	
ICD	1																						
Circulatory width	0.148	1.174	1																				
Entry width	0.168	1.202	0.189	1.233	1																		
Three-arm indicator	0.300	1.429	0.045	1.047	0.104	1.116	1																
Four-arm indicator	0.013	1.013	0.011	1.011	0.003	1.003	0.260	1.352	1														
Five-arm indicator	0.012	1.012	0.030	1.031	0.079	1.086	0.043	1.045	0.260	1.352	1												
Signalised indicator	0.053	1.056	0.165	1.197	0.142	1.166	0.014	1.015	0.018	1.019	0.090	1.099	1										
Un-signalised indicator	0.303	1.434	0.288	1.405	0.334	1.502	0.162	1.193	0.001	1.001	0.047	1.049	0.266	1.363	1								
Lane number indicator	0.039	1.040	0.158	1.187	0.246	1.326	0.108	1.121	0.010	1.010	0.017	1.017	0.207	1.261	0.305	1.438	1						
Type of grade indicator	0.820	5.55	0.092	1.102	0.098	1.109	0.436	1.772	0.130	1.150	0.000	1.000	0.060	1.063	0.235	1.308	0.081	1.088	1				
Truck percentage	0.042	1.043	0.030	1.030	0.004	1.005	0.000	1.000	0.000	1.000	0.012	1.012	0.010	1.010	0.003	1.003	0.001	1.001	0.051	1.053	1		
ln(AADT)	0.296	1.420	0.158	1.188	0.235	1.308	0.263	1.357	0.001	1.001	0.128	1.147	0.066	1.071	0.297	1.423	0.216	1.276	0.276	1.381	0.005	1.005	1

Table 5-1b R^2 and VIF Results of Correlation Between Independent Variables Within Circulatory Lanes

variable	ICD		Circulatory width		Signalised indicator		Un-signalised indicator		Lane number indicator		Type of grade indicator		Truck percentage		ln(AADT)
	R^2	VIF	R^2	VIF	R^2	VIF	R^2	VIF	R^2	VIF	R^2	VIF	R^2	VIF	
ICD	1														
Circulatory width	0.1482	1.1740	1												
Signalised indicator	0.0676	1.0725	0.1513	1.1783	1										
Un-signalised indicator	0.3434	1.5230	0.2098	1.2654	0.3215	1.4738	1								
Lane Number indicator	0.0942	1.1041	0.2460	1.3263	0.3969	1.6581	0.4007	1.6686	1						
Type of grade indicator	0.820	5.55	0.0924	1.1018	0.0671	1.0719	0.2601	1.3515	0.1116	1.1256	1				
Truck percentage	0.0412	1.0430	0.0296	1.0305	0.0045	1.0045	0.0029	1.0029	0.0035	1.0035	0.0506	1.0533	1		
ln(AADT)	0.2959	1.4203	0.1592	1.1893	0.0986	1.1094	0.2852	1.3989	0.2256	1.2914	0.2756	1.3805	0.0046	0.9954	1

Table 5-1c R^2 and VIF Results of Correlation Between Independent Variables at Approaches

variable	Entry width		Signalised indicator		Lane number indicator		Type of grade indicator		Truck percentage		ln(AADT)	
	R^2	VIF	R^2	VIF	R^2	VIF	R^2	VIF	R^2	VIF	R^2	VIF
Entry width	1											
Signalised indicator	0.198	1.247	1									
Lane Number indicator	0.283	1.395	0.213	1.270	1							
Type of grade indicator	0.077	1.084	0.169	1.203	0.021	1.021	1					
Truck percentage	0.099	1.109	0.069	1.074	0.071	1.076	0.011	1.011	1			
ln(AADT)	0.143	1.167	0.153	1.180	0.144	1.169	0.105	1.117	0.542	2.182	1	

According to the rule of thumb (VIF≥5), the results illustrated in Table 5-1a to 5-1c shows that no geometric and traffic variables are correlated to each other, except the grade-separated indicator for roundabouts as a whole and their circulatory lanes, which is highly correlated with their ICD (VIF=5.55). Previous studies (Retting, (2006), Arndt, (1998), and Rodegerdts et al., (2010) and (2007)) have found that a higher ICD correlates with a higher number of total accidents, so it is necessary in this study to examine the influence of ICD on total and truck accidents and compare the results with those of the previous studies. Consequently, the type of grade indicator was removed from the model, but in order to see the difference between grade-separated and at-grade roundabouts, a different model for whole roundabouts was developed separately for each type of grade, and they are illustrated in this chapter. This correlation analysis therefore confirms the findings of Chapter Four where it was identified that grade-separated roundabouts showed different trends from at-grade roundabouts, making it necessary to build a model for each type of grade separately.

5.3 Model Comparisons with Previous Roundabout Accident Prediction Models

A fixed-parameters NB model was applied to total accidents and compared with previous models, developed by different researchers of roundabouts. In this study, for the purpose of comparison, two different types of models were developed: firstly a traffic-flow-only model (the results for which are presented in Table 5-2); and secondly a traffic-flow and geometric-characteristics model for the selected locations across whole roundabouts, in circulatory lanes and at approaches (these results are presented in Table 5-3).

Previous accident prediction models from the literature are illustrated in Section 2.3.6.2 (Table 2-5). In general, all previous works presented in Table 2-5 were accident models based on either flow alone or flow and geometric variables together, and they applied standard NB distribution count data regression models to the data, except Arndt (1998) who used linear regression models.

In each model, the number of observations, country the study has been undertaken in, year of study, geometric variables, traffic variables, and roundabout category (i.e., either for the whole roundabout, or for entering-circulating or existing/circulating sections, or for approaches) are different relative to this study and relative to each other. In addition, each country has different design factors, and different environments, as well as probably different driver behaviours. These may be the main reasons that each model has developed different regression coefficients for traffic flow and geometric variables. Further discussion on the influence of geometric and traffic variables by previous studies can be found in Section 2.3.6.

Table 5-2 Results of Basic Total Accidents-Flow-only Models by Roundabout Category

Roundabout Catagory	Variable	NB Fixed Parameters Model	
		coefficient	*t*-stat
Whole Roundabout	**Constant**	-4.1491	-3.138***
	Traffic Characteristics ln(AADT)	0.7639	5.987***
	Dispersion parameter[31]	2.283	4.465***
	Number of roundabouts (observations)	70	
	Log-likelihood at constant only	-348.71	
	Log-likelihood at convergence	-340.53	
	ρ^2	0.023	
	AIC	685.06	
Within circulatory	**constant**	-7.009	-2.545***
	Traffic Characteristics ln(AADT)	0.912	3.508***
	Dispersion parameter	1.05	6.084***
	Observation numbers	70	
	Log-likelihood at constant only	-272.25	
	Log-likelihood at convergence	-263.93	
	ρ^2	0.031	
	AIC	531.86	
Approaches	**constant**	-4.7921	-5.673***
	Traffic Characteristics ln(AADT)	0.7485	8.162***
	Dispersion parameter	1.5761	9.351***
	Observation numbers	284	
	Log-likelihood at constant only	-933.11	
	Log-likelihood at convergence	-902.31	
	ρ^2	0.033	
	AIC	1808.62	

* At 90% significance level   ** At 95% significance level   *** At 99% significance level

From Table 5-2, the following equations for basic accident-flow models are drawn:

$$A_w = 1.577 \times 10^{-2} \times Q_w^{0.76} \quad (5\text{-}1)$$

$$A_c = 9 \times 10^{-4} \times Q_w^{0.912} \quad (5\text{-}2)$$

$$A_a = 0.83 \times 10^{-2} \times Q_a^{0.75} \quad (5\text{-}3)$$

where:

[31] Note Dispersion parameter shows that the variance in the data is greater than mean, statistically, and this indicated by t-stat. NB model requires a significant dispersion parameter (Washington et al., 2011).

A_w, A_c, and A_a = total accidents across the whole roundabout, in the circulatory lanes, and at the approaches respectively.

Q_w = the sum of entry flow across the whole roundabout.

$Q_{a=}$ is the entry flow at individual approaches.

1.577×10^{-2} ,9×10^{-4} and 0.83×10^{-2} are the exponentials of constants for whole, within circulatory lanes, and at approaches to the roundabouts, respectively.

Table 5-3 Results of Total Accident-Flow-Geometric Models by Roundabout Category

Roundabout Category	Variable	NB Fixed Parameters Model	
		coefficient	*t*-stat
Whole Roundabout	**Constant**	-1.938	-1.739*
	Geometric characteristics		
	ICD(m)	0.004	3.332***
	Un-signal indicator	-0.56	-3.790***
	Traffic characteristics		
	ln(AADT)	0.46	4.843***
	Percentage of Average Annual daily truck traffic	0.064	1.930*
	Dispersion parameter	4.162	4.821***
	Observation numbers	70	
	Log-likelihood at constant only	-348.71	
	Log-likelihood at convergence	-319.64	
	ρ^2	0.083	
	AIC	649.28	
Within circulatory	**Constant**	1.498	3.611***
	Geometric characteristics		
	ICD(m)	0.007	4.287***
	Traffic signal (1 if un-signal;0 otherwise)	-0.975	-3.828***
	Traffic Characteristics		
	Percentage of Average Annual daily truck traffic	0.058	1.648*
	Dispersion parameter	1.753	4.194***
	Observation numbers	70	
	Log-likelihood at constant only	-272.25	
	Log-likelihood at convergence	-248.34	
	ρ^2	0.087	
	AIC	504.68	
Approaches	**Constant**	-4.63	-4.848***
	Geometric characteristics		
	Lane number (1 if lane number=2;0 if 3)	0.217	1.785*
	Traffic signal (1 if signalised;0 if un-signalised)	0.181	1.682*
	Grade type (1 if grade-separated;0 if at-grade)[32]	0.804	6.174***
	Traffic Characteristics		
	ln(AADT)	0.63	6.091***
	Dispersion parameter	1.87	9.130***
	Observation numbers	284	
	Log-likelihood at constant only	-933.11	
	Log-likelihood at convergence	-880.912	
	ρ^2	0.055	
	AIC	1771.824	

* At 90% significance level   ** At 95% significance level   *** At 99% significance level

[32] At approaches type of grade included in the model because ICD does not included as a variable influencing approach accidents.

From Table 5-3, the following equations for accident-flow-geometric models are drawn:

$$A_w = 1.4 \times 10^{-1} \times Q_w^{0.46} \times e^{\sum 0.004\, ICD - 0.56\, unsignal_w + 0.064\, truck\_pc} \quad (5\text{-}4)$$

$$A_c = 4.47 \times e^{\sum 0.007\, ICD - 0.975\, unsignal_c + 0.058\, truck\_pc} \quad (5\text{-}5)$$

$$A_a = 9.8 \times 10^{-3} \times Q_a^{0.63} \times e^{\sum 0.217\, two\ lane_a + 0.181\, signalised_a + 0.804\, grade\ separated_a} \quad (5\text{-}6)$$

where:

ICD = ICD (m)

$unsignal_w$ = un-signalised whole roundabout

$unsignal_c$ = un-signalised circulatory

$truck\_pc$ = percentage of average annual daily truck traffic

$two\ lane_a$ = two-lane approaches

$signalised_a$= signalised approaches

$grade\ separated_a$= approaches that are located on grade-separated roundabouts

This study looks at the roundabouts in their entirety (approach and circulatory lanes), within the circulatory lanes, and at the approaches, and truck percentage in addition to AADT is added to the model. No previous studies added truck percentage as a factor for the total accident prediction models. It is important to include truck traffic percentage in accident prediction models at roundabouts because they are a part of traffic in the road network, and because of different size and weight and their different manoeuvres compared with other types of vehicles it is necessary to explore how they influence accidents. There are similarities and differences between the selections of geometric variables in this study compared with previous studies.

In this study, in order to compare the overall fit of the flow-only model to the flow-geometric model McFadden ρ^2 Eq. (3-13) and Akaike Information Criteria AIC Eq. (3-14) were identified for both models. This will indicate whether adding geometric variables to the flow-only model will improve the overall fit of the model. It was found that based on the value of ρ^2 the accuracy of the model improved for whole roundabouts, within circulatory lanes, and at approaches because higher number of ρ^2 were identified when geometric variables were added to the model (see Table 5-2 and Table 5-3). In addition, a lower value of AIC was identified for the flow-geometric model compared to flow-only model for whole, within circulatory lanes, and at approaches indicating better overall fit of the model. This supports the findings of Harper and Dunn (2005) who found that adding geometric variables in addition to traffic variables improves the accuracy of the predicted model.

AADT was found to be a significant variable for all models as an influence on total accidents: as traffic volume increased, accident numbers increased. A number of studies have developed total accident prediction models using flow as the only independent variable, for instance Maycock and Hall (1984), Guichet (1997), and Montella (2007) all of which have found that flow and accidents are highly positively correlated.

In this study, ICD was found to have a statistically significant, and possible, relationship with the number of accidents at whole roundabouts. Previously Rodegerdts et al. (2007) found that ICD increases exiting/circulating accidents, but the regression coefficient in the Rodegerdts et al. (2007) study was 0.022, which is higher than in this study. The probable reason is that Rodegerdts et al. (2007) found that ICD is associated with increasing accident rates when exiting/circulating, while in this study it is associated with increasing accident numbers in entering plus circulating traffic flows. In addition, sample size also affects these differences. And in the Maycock and Hall (1984) study it was found that the ratio of ICD to central island diameter was associated with higher rates of accidents at entering/circulating traffic flows.

Circulatory roadway width was found to have, statistically, an insignificant effect on accidents in this study, while Rodegerdts et al. (2007) and Harper and Dunn (2005) found that accidents increase as circulatory roadway width increases, as this increases the speed of vehicles and makes the roundabouts less safe. In contrast, Kim et al. (2013) have found that accidents decrease with higher circulatory roadway width.

The exploration of lane numbers within circulatory systems in this study using traditional NB models shows an insignificant effect on accidents, while Kim et al. (2013) found that an increasing number of lanes within the circulatory increase accidents.

Entry width, as explored in the Maycock and Hall (1984) and Rodegerdts et al. (2007) studies across the entering/circulating roundabouts was found to be, statistically, a significant variable, increasing the rates of accidents. However, Maycock and Hall (1984) found that at approaches wider entries corresponded to a lower risk of accidents, while Kim et al. (2013) have found that higher entry width is associated with an increase in accident number at approaches. In this study the standard NB models identify that entry width has, statistically, an insignificant influence on accident risks at approaches, and on whole roundabouts.

At approaches, Kim et al. (2013), Brude and Larsson (2000), and Šenk and Ambros (2011) found that approaches that have two-lanes have an increased rate of accidents compared to those with single lanes, and in this study two-lane entry, when compared with three-lane entry, was found to have a lower rate of accidents but at approaches these rates were close (a rate of 8.7 for two-lanes relative to a rate of 10.5 for three-lanes). However, based on the model results, two-lane approaches are associated with a higher number of accidents relative to three-lane approaches. When total accident number was related to AADT with respect to number of lanes (see Figure G-5 (left), Appendix G) it was found that the majority of three-lanes have the same level of traffic compared with two-lanes and the same level of accidents, and as AADT increases total accidents increase in both two and three-lane roundabouts. This is probably the reason for having high numbers of accidents in two-lane approaches. The influence of the number of arms was examined in this study, but according to the fixed-parameter NB model, statistically, an insignificant effect was found on the number of accidents. Brude and Larsson (2000) found that three-arm roundabouts have lower accident numbers than those with four or more arms, and Kim et al. (2013) and Shadpour (2012) found that accidents increase with the number of arms.

In this study, un-signalised whole roundabouts and un-signalised circulatory lanes were associated with lower numbers of accidents, while signalised approaches were associated with higher numbers of accidents. Signalisation had not been included as a variable in the previous models. Signalisation control on roundabouts is installed for the purpose of controlling congestion. Hence, as Figures G-3 (left), G-11 (left), and G-17(left) in Appendix G indicate, un-signalised whole roundabouts, un-signalised circulatory, and un-signalised approaches, respectively, exhibit lower traffic levels compared to other types of traffic control.

From the above results, it can be concluded that, based on the fixed-parameter NB models identified for the selected roundabouts, AADT and ICD show the same influence on total accidents as previous studies; however adding variables, for instance signalisation, for the whole roundabout, within circulatory lanes, and at the approaches, and adding the type of grade of the approach to the model probably renders the other geometric variables like entry width and circulatory roadway width insignificant, which resulted in seeing a different relationship of these parameters to total accident occurrences.

Note that this standard model that has been used in this section is not the final research model, and it is examined in order to compare the findings of this study with those from previous studies.

5.4 Total Accident Prediction Model

The objective of the analysis was to relate the total number of accidents to a range of explanatory variables, and hence to determine a relationship which could be used to predict site-specific accident risks. The method used is the random-parameters NB distribution and it is compared with the fixed-parameters NB distribution used in Section 5.3. In addition, grade-separated locations were analysed separately from at-grade locations for the reason described in the Section 5.1. The main aim of this section is to build a reliable total accident model and to find the influence of the exposure variables (i.e. traffic and geometric characteristics) affecting accident occurrences at roundabouts in three different groupings (roundabouts as a whole, within circulatory lanes, and at approaches).

The random and fixed parameter NB model estimation results are shown in Table 5-4 for the whole roundabouts, within the circulatory lanes, and at the approaches. Table 5-5 gives the average marginal effects estimated by the models.

For the whole roundabout, Table 5-4 shows that the random-parameters NB model results in an improvement in the log-likelihood at convergence, from -319.6350 in the fixed-parameters model to -317.0940 in the random-parameters case. For the whole roundabout, the resulting χ^2 Eq. (3-12) was 5.082 with one degree of freedom[33]. This indicates that the random parameters model is statistically better than the fixed parameters model at a level of confidence interval of 98%. Based on the likelihood ratio test the improvement in the random parameter model is significant at a *p*-value of 0.05.

The effect of a variable varies across observations (i.e. a variable is considered to have a random effect on total accidents across the roundabouts) when the SD of the parameter is statistically found to be different from zero, for the variables that are random in this study a SD is attached to their mean see Table 5-4.

[33] Degree of freedom equals the number of random parameters in the model.

Table 5-4 Total Accident Model Estimation Results

Roundabout Category	Variables	NB Random-parameters model		NB Fixed-parameters model	
		coefficient	*t*-stat	coefficient	*t*-stat
Whole roundabout	**Constant**	-1.45	-1.698*	-1.938	-1.739*
	Geometric characteristics				
	ICD	0.005	6.125***	0.004	3.332***
	Traffic signal (1 if un-signal;0 otherwise)	-0.577	-5.793***	-0.56	-3.790***
	Traffic Characteristics				
	ln(AADT)	0.403	4.951***	0.46	4.843***
	Percentage of average annual daily truck traffic	0.06	4.404***	0.064	1.930*
	SD	0.055	8.664***		
	Dispersion parameter	10.35	4.453***	4.162	4.821***
	Observation numbers	70			
	Log-likelihood with constant only	-348.7167			
	Log-likelihood at convergence	-317.0940[34]		-319.6350	
Within circulatory lanes	**Constant**	1.087	2.628***	1.498	3.611***
	Geometric characteristics				
	ICD(m)	0.007	4.744***	0.007	4.287***
	Traffic signal (1 if un-signalised;0 otherwise)	-1.267	-6.107***	-0.975	-3.828***
	SD	*0.827*	*5.845****		
	Traffic Characteristics				
	Percentage of average annual daily truck traffic	0.084	2.39**	0.058	1.648*
	Dispersion parameter	3.0163	3.535***		
	Observation numbers	70			
	Log-likelihood with constant only	-272.2513			
	Log-likelihood at convergence	-241.4268		-248.3459	
At approaches	**Constant**	-4.858	-5.678***	-4.634	-4.848***
	Geometric characteristics				
	Lane number (1 if lane number=2;0 if 3)	0.164	1.551	0.217	1.785*
	SD	*0.409*	*6.745****		
	Traffic signal (1 if signalised;0 if un-signalised)	0.238	2.420**	0.181	1.682*
	Grade type (1 if grade-separated;0 if at-grade)	0.712	6.011***	0.80	6.174***
	SD	0.214	4.352***		
	Traffic Characteristics				
	ln(AADT)	0.66	7.067***	0.63	6.091***
	Dispersion parameter	2.57	8.547***	1.87	9.130***
	Observation numbers	284			
	Log-likelihood with constant only	-933.1128			
	Log-likelihood at convergence	-879.1532		-880.9199	

* At 90% significance level ** At 95% significance level *** At 99% significance level

[34] Significantly different log-likelihoods are shaded.

Table 5-5 Total Accident Average Marginal Effects Results

Roundabout Category	Variable	NB Random-parameters model	NB Fixed-parameters model
Whole roundabouts	ICD (m)	0.227	0.205
	Traffic signal (1 if un-signal;0 otherwise)	-26.41	-27.55
	ln(AADT)	18.43	22.89
	Percentage of Average annual daily truck traffic	2.77	3.16
Within circulatory	ICD (m)	0.083	0.084
	Traffic signal (1 if un-signal; 0 if signalised)	-13.57	-12.4
	Percentage of Average Annual Daily Truck Traffic	0.90	0.748
At approaches	Lane number (1 if lane number=2; 0 if 3)	1.25	1.76
	Traffic signal (1 if signalised; 0 if un-signalised)	1.81	1.47
	Grade type (1 if grade-separated; 0 if at-grade)	5.40	6.52
	ln(AADT)	5.00	5.14

For the data within the circulatory lanes, Table 5-4 illustrates that log-likelihood at convergence for the random-parameters NB model is significantly better compared to the fixed-parameters model. The resulting χ^2 was 13.8382 with one degree of freedom, giving a 99.99% confidence that the random-parameters model is statistically better, and the likelihood ratio test suggesting that the improvement in the model is significant at a *p*-value of 0.0001.

At approaches, there is a small improvement in log-likelihood at convergence for the random parameters model when it is compared to the fixed parameters model. The likelihood ratio test gave a χ^2 of 3.5334 with two degrees of freedom indicating an 83% confidence that the random-parameters model has a better overall fit, but this percentage alone is not enough to justify adoption of the random-parameters model. However, because the random-parameters model has lower log-likelihood (-879.1532 compared to -880.9199), it can be used as a better model, and from the relationship between actual and predicted values (see Figure 5-3) an improvement can be noticed in predicted accidents comparing random to fixed-parameters models.

Predicted Value vs Actual Accident Numbers

Figures 5-1 through 5-3 present predicted values compared with actual values for random and fixed-parameters models for the different roundabout categories (whole, circulatory lanes, and approaches). It is apparent that the overall fit of the random-parameters models is better. It is the fact that within the circulatory lanes there is not much difference between the two models when actual value related to predicted value and the reason is that all the variables were found to be statistically highly significant in random and fixed parameters models, which probably leads to the same prediction. For the circulatory lanes and at approaches, a lower R^2 value was acquired in comparison with whole roundabouts in the random-parameters models. This indicates that the geometric and traffic variables for whole roundabouts (approaches and circulatory) are highly related to accidents, while within the circulatory lanes and at approaches the geometric and traffic variables affecting accidents are not as highly related, as indicated by R^2. This means there may be other variables, (for instance speed of vehicles, driver behaviour, pavement condition, etc...) that affect accident occurrences and which might enhance the model, permitting better prediction of accidents.

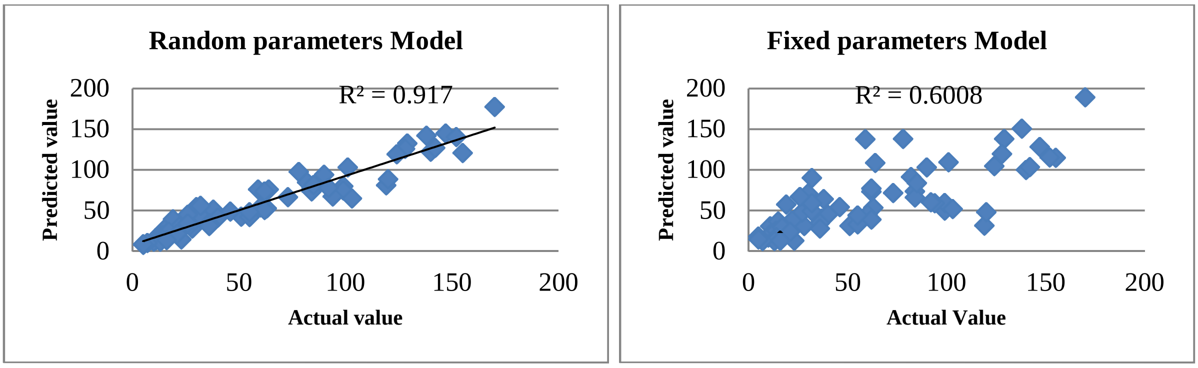


Figure 5-1 Predicted and Actual Number of Total Accidents for Whole Roundabouts

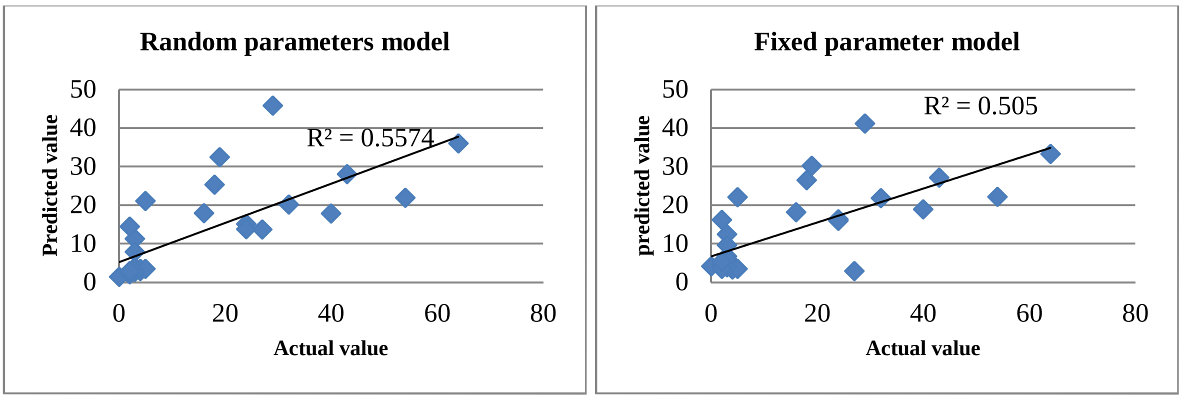


Figure 5-2 Predicted and Actual Number of Total Accidents for Circulatory Lanes

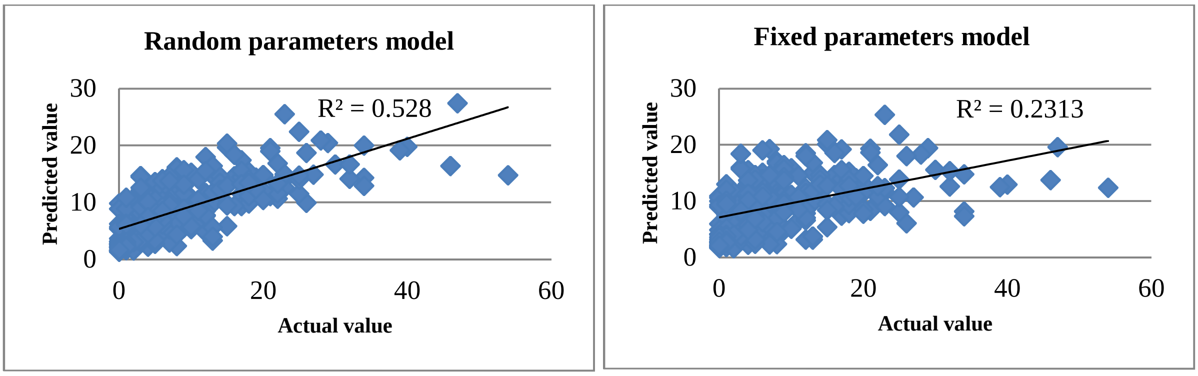


Figure 5-3 Predicted and Actual Number of Total Accidents for Approaches

For each roundabout category all the geometric and traffic variables presented in Tables 3-9a to c, except type of grade for the whole roundabout, and within circulatory lanes, were tested in order to find their significance. The following variables were found statistically to have a random effect across the observations:

- Percentage of truck traffic across the whole roundabout,
- Un-signalised circulatory lanes, and
- Two-lane indicator and grade-separated indicator at approaches to roundabouts.

As stated in the model development method in Section 2.1.5, a parameter is considered random when the SD of the parameter distribution is significantly different from zero (if the estimated SD of the variable is not significantly different from zero, the variable is considered to be fixed across the observations) and this can be indicated by *t-stat* of the SD of the random parameters reported in Table 5-4, in this study three *t-stat* were used (1.65, 1.98, and 2.58).

The following variables were found to be fixed in the random parameters-models and their effect was statistically significant as indicated by the *t*-statistic (see Table 5-4):

- Un-signalised whole roundabouts,
- ICD of the roundabout at whole roundabouts and within circulatory lanes,
- Signalised approaches,
- AADT for whole roundabouts and at approaches, and

- Truck percentage within the circulatory lanes.

For the whole roundabout, the effect of percentage of average annual daily truck traffic was found to vary across the roundabouts and have a normal distribution with a mean of 0.06 and SD of 0.055. Given these parameters, 14% of the distribution is less than 0 (which means only 14% of the roundabouts had a lower number of accidents with higher truck percentage), and 86% is greater than 0 (which means that the majority of the roundabouts with higher truck percentages had a higher number of accidents). This result indicates that the majority of the roundabouts experience an increase in accidents as the percentage of truck traffic increases. According to Table 5-5, the random parameters marginal effects indicate that a 1% increase in truck traffic will increase the number of accidents by 2.77% (in the fixed-parameters model the accident number increases by an average of 3.16%). 14% of the locations is equivalent to nine locations with lower accident numbers with higher truck percentages; going back to the data it was found that these roundabouts are Chester Road on the A5, Lodge Lane on the A5, Mytton Oak Road on the A5, A19/A645, A5/A361, A19/Thirsk Road, A63/A19, A616/A6075, and A1246/A63. It can be seen that these are all at-grade roundabouts which are smaller than the grade-separated roundabouts. At such roundabouts (the majority of them are small roundabouts) the higher percentage of truck traffic might lead other vehicles to drive more carefully, or the presence of trucks in the road may lead to greater driver awareness of the hazards. Milton and Mannering (1998) and Miaou (1994) found that total accident rates decrease with an increasing percentage of truck traffic, with the authors stating that with a higher percentage of trucks, a lower number of other vehicles will change their lane and overtake, leading to a lower accident rate; however they found this in three-lane road segments, while in our study this phenomena were identified in at-grade roundabouts. In contrast Dong et al. (2014) have stated that increasing truck percentage at roadway segments changes the behaviour of other drivers to more regularly change lanes, which leads to higher accident risks.

Increasing ICD was found to relate statistically with high significance, to an increasing number of accidents. Higher diameter roundabouts also have higher numbers of arms, although arm numbers were found to have, statistically, an insignificant effect on increasing accidents. According to Table 3-9a the average ICD for the selected locations is 158m, so it is more appropriate to explain the results with respect to 10 m increase in ICD. Therefore, Table 5-5, shows that 10 m increase in ICD was associated with an increase in accidents by an average of 2.2 over the 11-year period (which is close to the fixed-parameters model's average of 2.1). Previous studies (Retting, 2006; Arndt, 1998; and Rodegerdts et al., 2007, and 2010) have found that, smaller ICD improves the safety of the roundabouts, as this will help maintain lower speed, and hence provide safety for roundabouts. And, Daniels et al. (2010) found that ICD has no effect on total accidents. One point should be taken into account, that previous studies did not report marginal effects, and they drew their conclusions according to the statistical significance of the parameter in the model.

Un-signalised roundabouts were found to have a statistically significant effect on the number of accidents: it was found that roundabouts that are un-signalised were associated with lower numbers of accidents by an average of 26.41 over the 11-year period (the fixed-parameters model showed an average of 27.55). Note that the majority of the locations that are un-signalised are at-grade roundabouts. This means that signalised and partially signalised roundabouts have a higher number of accidents and, as found in Chapter Four, the casualty trend for traffic control (Figure 4-16) indicates that partially signalised roundabouts see the highest number of casualties, followed by signalised roundabouts. However, according to accident severity, a higher proportion of accidents results in fatalities at un-signalised roundabouts (1.97%), followed by partially signalised (1.03%) and signalised roundabouts (0.66%). In addition, as discussed in an earlier section 5-2, and in Section 4.5.1, that un-signalised roundabouts are associated with lower total accidents, because they have lower traffic levels relative to signalised and partially signalised roundabouts.

As AADT is entered to the model in logarithmic form[35], their estimated coefficient indicates the elasticity of total accidents regarding AADT, which means a 1% increase in AADT leads to a 0.40% increase in the predicted number of accidents see Table (5-4). It is a well-known fact that as AADT increases, accidents increase, as has been found by many researchers (for instance: Maycock and Hall, 1984; Daniels et al., 2010; Šenk and Ambros, 2011; Rodegerdts et al., 2007; Shadpour, 2012; Guitchet, 1997; Montella, 2007; Harper and Dunn, 2005; Turner et al., 2006). In addition, the HSM uses traffic volume as the major exposure variable in its models (AASHTO, 2014).

Within the circulatory lanes, the effect of un-signalised traffic was found to vary across the roundabout circulatory lanes having a normally distribution with a mean of -1.267 and a SD

[35] The estimated marginal effect for AADT is based on one unit change in ln(AADT) because AADT entered the model as natural logarithm, and converting one unit change in ln(AADT) (i.e ln(AADT) of 8 to ln(AADT) of 9, or ln(AADT) of 5 to ln(AADT) of 6) leads to 172% or (1.72) change in actual value of AADT. As 172% increase in AADT is huge amount change in traffic so it was more convenient to interpret the change based on the regression coefficient (or elasticity at the conditional mean).

of 0.827, resulting in 94% of the un-signalised circulatory lanes distribution being less than 0 and 6% greater than 0. This indicates that most of the un-signalised circulatory lanes are associated with lower numbers of total accidents. The average marginal effect for the un-signalised indicator in the random-parameters model shows that accidents decrease by 13.57, while in the fixed-parameters model the accidents decrease by 12.4. Note that there are 30 roundabouts with un-signalised circulatory lanes and 28 (94%) of them have lower numbers of accidents while the other two (6%) have higher numbers of accidents, these locations are J17 on the M4 (grade-separated) and A607/A46 (at-grade). Note that these two locations constitute higher AADT compared with others. The probable reason for un-signalised circulatory being safer is that the majority of them are at-grade roundabouts, and lower numbers of accidents are recorded at at-grade roundabouts. In addition, the majority of un-signalised circulatory lanes have lower traffic levels compared with other types of traffic control (see Figure G-11 (left), Appendix G).

Within the circulatory lanes, a 10 m increase in ICD leads to an accident increase of 0.83 in the random-parameters model over the 11-year period (this number was 0.84 in the fixed-parameters model), as seen in Table 5-5. This increase is not high according to the marginal effect, over 11-year period. Maycock and Hall (1984) found that the higher the ratio of ICD to central island diameter, the higher the accident rates. Moreover, Rodegerdts et al. (2010) stated that higher ICD decreases vehicle deflection and hence increases speeds of vehicle leading to higher exiting/circulating accidents.

AADT was found to be insignificant within the circulatory lanes, but the percentage of truck traffic was found to have a highly significant effect on the number of accidents. And this supports the findings of the linear relationship between total accidents and percentage of truck traffic within circulatory lanes (see Section 4.5.2) as for the majority of roundabout categories a significant linear relationship was identified between the two. A 1% increase in the truck traffic percentage in the random parameters model increases the predicted accident numbers by an average of 0.90% and an average of 0.75% in the fixed-parameters model.

At approaches, it was found that entry width has, statistically, an insignificant effect on the number of accidents. Having two-lanes was found to produce, statistically, a random parameter with SDs statistically different from zero. On more than half of the approaches with two-lanes (66%) there is an increased number of accidents, by an average of 1.25 over the 11-year period (see Table 5-5) (the average marginal effect was 1.76 in the fixed-parameters model). In total there are 172 two-lane approaches, 107 of them are located on A-class roads, 53 on M-class roads, and 12 are on B class roads. Of the 172 approaches with two-lanes 58 (34%) of them had lower numbers of accidents, according to the distribution of the indicator. It was found that:

- 17 approaches recorded zero accidents and all are located on A-class roads except one approach which is located on a Motorway.
- 16 approaches recorded one accident and all are located on A- and B-class roads except three approaches located on Motorways.
- 14 approaches recorded two accidents and all are located on A- and B-class roads except one approach which is located on a Motorway.
- 11 approaches recorded three accidents and all are located on A- and B-class roads except one approach which is located on a Motorway.

This shows that out of 58, 52 approaches that recorded a lower number of accidents are located on A-class roads, and the other six are located on M-class approaches. these M-class approaches are located on the east of J14 on the M4, north of J23 on the M1, south of J27 on the M1, west of J9 on the M53, west of J23 on the M4, and south of J4 on the M53. Note that the majority of two-lane approaches have the same level of traffic as three-lane approaches and recorded high accidents (see Figure G-15 (left), Appendix G). Previous studies, e.g. Daniels et al. (2010), found that the number of lanes has no effect on whole roundabout total accidents, in addition the effect of lane numbers on total accidents was considered fixed across the observations as indicated by Brude and Larsdson (2000), Kim et al. (2013), and Shadpour (2012), who all found that a higher number of entry lanes is related to higher total accidents relative to single-lane approaches.

Signalised approaches were found to have a significant effect on increasing the number of accidents. Table 5-5 shows that accidents increase by 1.81 (1.47 in the fixed-parameters model) with signalised approaches. Note that Figure G-17 (left) (Appendix G) indicates that un-signalised approaches have lower AADT which corresponded to a lower number of total accidents, while signalised approaches have higher accident counts. All signalised approaches were found to have significant effect on increasing the number of accidents. However, this result is in contrast to the UK Department of Transport (2009) which states that accidents decrease when roundabouts are signalised, as signals regulate the speed of traffic. Presumably this apparent contrast is because those junctions that have been modified exhibited accident rates at the higher end of the range before being signalised and, while the act of signalisation reduced the accident rates at those roundabouts, the act was not sufficient to bring the rate down to a value exhibited by those roundabouts less in need of signalisation.

99.99% of the approaches that are located on grade-separated roundabouts have higher numbers of accidents than on approaches of at-grade roundabouts. Accidents at the former increase by an average of 5.40 (and by 6.52 in the fixed-parameters model); the probable reason is that those roundabouts that are grade-separated are at motorway junctions that handle high traffic volumes, as well as having four, five and six-arms. However, Figure 4-19 (left) indicates that, at approaches when total accidents are related to AADT, approaches that are located in at-grade roundabouts have lower numbers of total accidents compared to the approaches that are located in grade-separated roundabouts with the same traffic level. As discussed in Section 4.5.3, the probable reason is that approaches that are located on grade-separated roundabouts are either located on M or A-class roads, and the traffic level of the approaches that are located on A-class roads is close to the traffic level seen at at-grade roundabouts.

AADT has a fixed effect on the occurrence of accidents at a 99% confidence level, which means that the vast majority of the roundabout approaches experience accident increases as AADT increases. A 1% increase in AADT results in a 0.66% increase in the predicted accident numbers. Percentage of truck traffic was found to have an insignificant effect on total accidents at approaches; it appears from this analysis therefore that trucks have a greater impact on total vehicle accidents in circulatory lanes rather that at approaches.

5.5 Models for Total Accidents at Grade-Separated Roundabouts

As illustrated in the discussion in Section 5.2 on the correlation between independent variables, ICD was highly correlated to the grade-separated indicator variable; in addition, in Chapter Four, it was identified that at-grade roundabouts showed a different trend from grade-separated roundabouts. For this reason, the grade-separated variable was excluded from the models of whole roundabouts and the circulatory lanes. Therefore, in order to explore how the number of accidents are related to traffic and geometric characteristics at grade-separated roundabouts a random parameter NB model was used to estimate total accidents and the results are illustrated in this section. This model was then compared to the model identified for at-grade roundabouts illustrated in the next section.

Table 5-6 illustrates the prediction model for total accidents for grade-separated roundabouts for random and fixed-parameters models, and Table 5-7 shows the marginal effects of each of the variables in both models. For the whole roundabout, Table 5-6 shows that the random-parameters NB model results in an improvement in the log-likelihood at convergence from -237.4801 in the fixed-parameters model to -236.2521 in the random-parameters case. The resulting χ^2 Eq. (3-12) was 2.456 with one degree of freedom. This indicates that there is an 88% confidence that the random-parameters model is statistically better than the fixed-parameters model. However, 88% confidence is not significant at any significance level, but the random-parameters model is considered a better model with regard to its lower log-likelihood function and a better relationship between actual value and predicted value, as illustrated in Figure 5-4.

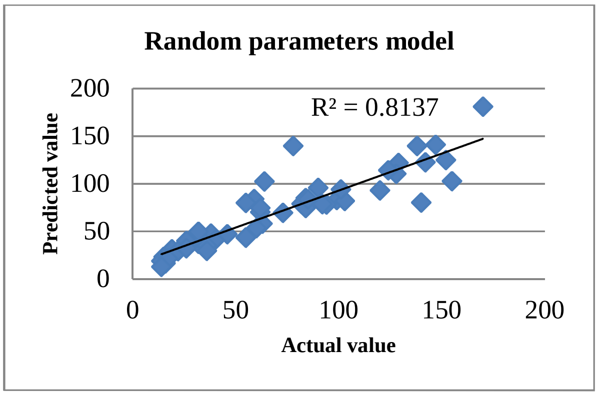
Table 5-6 Total Accident Model Estimation Results for Random and Fixed-Parameters NB Models at Grade-Separated Roundabouts

Variables	NB Random-parameters model		NB Fixed-parameters model	
	coefficient	*t*-stat	coefficient	*t*-stat
Constant	-1.902	-1.651*	-1.34	-0.873
Geometric characteristics				
ICD	0.005	5.001***	0.007	3.635***
Traffic signal (1 if un-signal;0 otherwise)	-0.609	-4.994***	-0.566	-3.658***
Four-arm indicator	0.097	0.851	0.157	0.823
SD	0.383	5.674***		
Traffic Characteristics				
ln(AADT)	0.40	4.218***	0.34	2.817***
Percentage of average annual daily truck traffic	0.065	4.207***	0.063	2.018**
Dispersion parameter	12.17	3.730***	6.04	3.258***
Observation numbers	51			
Log-likelihood at constant only	-260.5514			
Log-likelihood at convergence	-236.2521		-237.4801	

* At 90% significance level ** At 95% significance level *** At 99% significance level

Table 5-7 Average Marginal Effects Results for Grade-Separated Roundabouts

Variable	NB Random-parameters model	NB Fixed-parameters model
ICD (m)	0.40	0.47
Traffic signal (1 if un-signal;0 otherwise)	-36.7	-35.7
Four-arm indicator	5.9	9.9
ln(AADT)	24.3	21.5
Percentage of average annual daily truck traffic	3.97	3.98



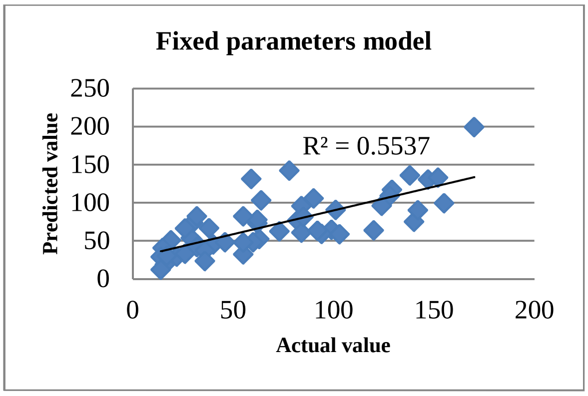


Figure 5-4 Predicted and Actual Number of Total Accidents for Grade-Separated Roundabouts

All the traffic and geometric parameter variables presented in Table 3-9a, (except type of grade and the three-arm indicator) were tested in order to find their significance on total accidents. Note that because all three-arm roundabouts are at-grade, they were excluded from the analysis. The following variables were found to be statistically significant but their effects remained fixed across the observations:

- ICD,
- Un-signalised grade-separated roundabouts, and
- AADT and percentage of truck traffic.

The four-arm indicator was found to vary across the grade-separated roundabouts as indicated by *t-stat* of the SD shown in Table 5-6; however, for all 70 roundabouts the number of arms was found to have an insignificant effect on accident occurrences. 40% of the distribution is less than 0 (which means that 40% of the roundabouts that have four-arms had a lower number of accidents), and 60% is greater than 0 (which means that the majority of the four-arm grade-separated roundabouts have higher numbers of accidents). This result indicates that the majority of the four-arm roundabouts experience an increased number of accidents. In addition, researchers have found that as the number of arms increases, accidents increase (Kennedy, 2007; Kim et al., 2013; Shadpour, 2012). The four-arm indicator in the fixed-parameters model was found to be statistically insignificant as indicated by the *t*-statistic (see Table 5-6), and this provides support for using the random-parameters NB model. According to Table 5-7, the random-parameters marginal effects indicate that the four-arm indicator is associated with a higher number of accidents by an average of 5.9 accidents. However, of 51 grade-separated roundabouts, 35 of them have four arms and 14 (40%) of these four-arm roundabouts have lower accident rates with the four-arm indicator relative to 21 (60%) of the other four-arm roundabouts. In addition, 338 accidents were recorded at the 14 four-arm roundabouts (a rate of 24 accidents per roundabout), while 1,830 accidents at the other 21 four-arm roundabouts (a rate of 87 accidents per roundabout). The roundabouts with lower accidents and four-arms are Gildabrook, J9 on the M53, M42/A441, and J18 on the M4, J2 on the M5, J3 on the M5, J23, J26, and J27 on the M1, J14 on the M4, J13 on the M6, M574/M62, A607/A46, and A606/A46. Of these, two are signalised, eight are un-signalised, and the other four are partially signalised. Note that the majority of these roundabouts are un-signalised, and have lower AADT, and this explains the lower total accident rates in these locations. The commonalities between these roundabouts are that they have approximately the same truck traffic percentage and entry width. The remaining grade-separated roundabouts are nine five-arm roundabouts with 575 accidents (a rate of 64 per roundabout) and seven six-arm roundabouts with 884 accidents (a rate of 147 accidents per roundabout).

ICD was found to have a statistically highly significant effect on the number of accidents. As the diameter increases, the number of accidents at a roundabout increases. However, this can be expected as all grade-separated locations have large diameters and diameter increases with increasing arm numbers. Regarding the average marginal effect in Table 5-7, 10 m increase in ICD of grade-separated roundabouts increased accidents by an average of 4 over the 11-year period (and in the fixed-parameters model average of 4.7). This effect doubled compared to the models that use all 70 roundabouts, as the effect for all 70 locations saw an increase in the average of 2.2.

Un-signalised, grade-separated roundabouts were found to be statistically associated with lower numbers of total accidents by an average of 36.7 over the 11-year period (in the fixed-parameters model the average is 35.7). In contrast, TLSM (2005) found that at at-grade and grade-separated roundabouts, total accidents decreased when they are signalised. All but one of the un-signalised grade-separated roundabouts has four-arms, with the exception having six. Note that grade-separated roundabouts include 13 un-signalised, 18 signalised and 20 partially signalised roundabouts. In addition, 454, 1,473, and 1,738 accidents were recorded at un-signalised, signalised, and partially signalised grade-separated roundabouts, respectively, (giving rates of 35, 82, and 87, accidents per roundabout, respectively). This means that signalised and partially signalised roundabouts have higher accident rates.

AADT is entered in logarithmic form, according to the regression coefficient presented in Table 5-6, a 1% increase is associated with 0.40% increase in the expected number of accidents, which is the same percentage figure that was found for all 70 roundabouts. The percentage of truck traffic was found to have a highly significant effect on the number of accidents; a 1% increase in truck traffic is associated with an increase in the predicted number of accidents by an average of 3.97% in the random-parameters model, a result reflected in the fixed-parameters model which gives an average of 3.98%. While the effect of truck percentage was found to be fixed across all grade-separated roundabouts, for all roundabouts this effect was random. This shows that the effect of truck percentage on truck accident is vary across at-grade locations, and more details of this effect for at-grade locations are presented in the next section.

5.6 Models for Total Accidents at At-Grade Roundabouts

This section illustrates the random-parameters models that are computed for at-grade locations (19 roundabouts), and is compared to the fixed-parameters models. The principal aim is to examine the influence of the geometric and traffic variables in at-grade locations on total accidents and to compare the results with locations that are grade-separated and with the all 70 roundabouts models.

Table 5-8 illustrates the prediction model for total accidents in at-grade roundabouts for the random and fixed-parameters models, and Table 5-9 shows the marginal effect of each model. Table 5-8 shows that log-likelihood at convergence improved from -74.449 in the fixed-parameters model to -73.927 in the random-parameters case. The resulting χ^2 Eq. (3-12) was 1.044 with one degree of freedom. Therefore, the random-parameters model is statistically better than the fixed-parameters model at 69% confidence level. This level is not significant at any significance level (i.e 90%, 95%, and 99%), but the random-parameters model is considered a better model with regard to a lower log-likelihood function and a better relationship between actual and predicted values as illustrated in Figure 5-5, which shows that actual values are highly correlated to predicted values, and this shows the improvement in the model relative to the fixed-parameter model.

Table 5-8 Total Accident Model Estimation Results for At-Grade Roundabouts

Variables	NB Random-parameters model		NB Fixed-parameters model	
	coefficient	*t*-stat	Coefficient	*t*-stat
Constant	-3.803	-2.086**	-7.645	-2.568**
Geometric characteristics				
Traffic signal (1 if un-signal;0 otherwise)	-0.84	-4.398***	-0.77	-2.359**
Traffic Characteristics				
ln(AADT)	0.73	4.013***	1.13	3.595***
Percentage of average annual daily truck traffic	0.015	0.396	-0.007	-0.085
SD	0.059	5.186***		
Dispersion parameter	12.23	1.851*	3.25	1.524
Observation numbers	19			
Log-likelihood with constant only	-83.46			
Log-likelihood at convergence	-73.927		-74.449	

* At 90% significance level ** At 95% significance level *** At 99% significance level

Table 5-9 Total Accident Average Marginal Effects Results for At-Grade Roundabouts

Variable	NB Random-parameters model	NB Fixed-parameters model
Traffic signal (1 if un-signal; 0 otherwise)	-17.43	-18
ln(AADT)	15	2
Percentage of Average annual daily truck traffic	0.32	-0.17

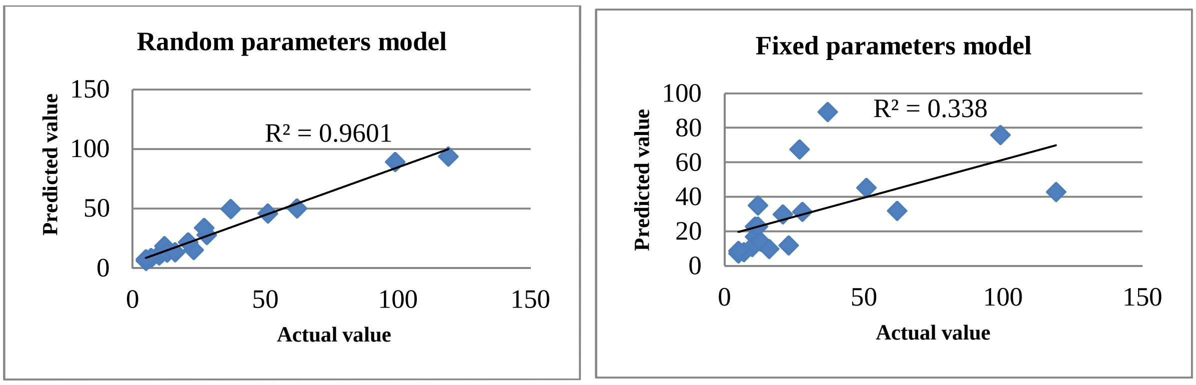


Figure 5-5 Predicted and Actual Number of Total Accidents for At-Grade Roundabouts

All the variables illustrated in Table 3-9a except type of grade indicator was examined to find their influence on truck accidents at grade-separated locations. And as the majority of at-grade roundabouts have three arms, only the effect of the three-arm indicator was tested (i.e. for arm indicator [1 if three; 0 if four and greater]) and it was found to be statistically insignificant. The following variables were found to be statistically significant but their effect remained fixed across the observations:

- Un-signalised at-grade roundabouts, and
- AADT in at-grade roundabouts.

The effect of percentage of average annual daily truck traffic varied across the at-grade roundabouts having a normal distribution with a mean of 0.015 and a SD of 0.059. Given these parameters, 49% of the roundabouts had a lower number of accidents with higher truck percentages), and the other 51 of the at-grade roundabouts with higher truck percentages had a higher number of accidents thus percentage of truck traffic is hardly related to accidents. The significance of the percentage of truck traffic in the fixed-parameters model was found to be negative and was insignificant as indicated by the *t*-statistic (see Table 5-8). According to Table 5-9, the random parameters marginal effects indicate that a 1% increase in truck traffic will increase the number of accidents by 0.319%. However, 49% of the locations means that nine at-grade roundabouts have lower accidents with higher truck percentage, and these roundabouts are Chester Rdn on the A5, Lodge Lane on the A5, Mytton Oak Road on the A5, A19/A645, A5/A5/A361, A19/Thirsk Road, A63/A19, A616/A6075, and A1246/A63 and they are un-signalised. This corresponds to the accident prediction models for all 70 roundabouts, where the same locations were found to have lower numbers of accidents with higher truck percentages. The impact of grade type therefore has much greater impact on accident likelihood than does the truck percentage.

It was found that at-grade roundabouts that are un-signalised have reduced accident numbers, by an average of 17.43 over the 11-year period (in the fixed-parameters model the average is 18.2). Note that 344, 99, and 126 accidents were recorded at 15 un-signalised, two signalised, and two partially signalised at-grade roundabouts, respectively, (rates of 23, 50, and 63 accidents per roundabout, respectively). This means that signalised and partially signalised roundabouts have higher rates of accidents.

AADT is entered in logarithmic form, and according to the regression coefficient presented in Table 5-8 a 1% increase leads to a 0.73% increase in the expected number of accidents, which is higher than the percentage increase that was found for all 70 and for grade-separated roundabouts. This indicates that accidents in at-grade roundabouts are more influenced by AADT than geometric parameters and percentage of truck traffic. And based on the results of the linear regression in Table 4-13 for whole roundabouts 36% of the variation in total accidents can be explained by the variation of AADT at at-grade roundabouts.

5.7 Truck Accident Prediction Model

The main objective of this section is to create a model for truck accidents and hence compare the results with the truck HBI models, in order to decide whether truck position data (i.e. HBIs) has the ability to predict accident risk at roundabouts. The secondary objective is to develop a suitable model for truck accident prediction across the selected roundabouts and to identify the significance of the exposure variables (traffic and geometric characteristics) on truck accidents across the selected roundabouts. As for total accident models, the roundabouts are analysed in three different categories: the whole roundabout, within the circulatory lanes, and at approaches.

Tables 5-10 and 5-11 present the model estimation results and average marginal effect of truck accidents for random- and fixed-parameters NB models. For the whole roundabout the results imply that the random-parameters model is statistically better than the fixed-parameters model according to the log-likelihood test ratio, the χ^2 statistic value of 5.139 with three degrees of freedom gives 84% confidence that the random-parameters model is better than the fixed-parameters model; this implies that the model is not justified at 90%, 95% and 99% levels. It can be used as a better model as most of the geometric variables were found to have an insignificant effect in the fixed-parameters model, while they were significant in the random-parameters model, and the random-parameters model considerably improved the predicted value versus the actual value relative to the fixed-parameters model (see Figure 5-6).

Within the circulatory lanes, an improvement can be seen in the log-likelihood in the random-parameters model (-153.3013) relative to the fixed-parameters model (-154.7943). According to the log-likelihood test ratio the χ^2 statistic value of 2.986 with one degree of freedom gives 92% confidence that the random-parameters model is better than the fixed-parameters model, and it is significant at a *p*-value of 0.01 (90% significance level). Figure 5-7 shows the relationship between actual values and predicted values for the random and fixed-parameters models. Because all the variables were found to be significant in both models, there is little difference between how the predicted values for the random and fixed-parameters models relate to the actual values. The resulting R^2 value for both models is not high compared to the whole roundabouts; this indicates that in addition to the geometric and traffic factors within the circulatory lanes, there are more factors influencing these truck accidents which may be related to driver behaviour, vehicle speed, pavement condition, road marking which could improve the prediction value if included. However, these factors were not addressed in this study so it is recommended that, as far as accidents within the circulatory lanes concerned, more factors as speed, pavement condition, and road marking might be included for prediction of truck accidents.

Table 5-10 Truck Accident Model Estimation Results

Roundabout Category	Variables	NB Random-parameters model		NB Fixed-parameters model	
		coefficient	*t*-stat	coefficient	*t*-stat
Whole roundabout	**Constant**	-3.82	-2.85***	-4.77	-2.351**
	Geometric characteristics				
	ICD	0.005	4.128***	0.004	2.419**
	Circulatory roadway width	-0.152	-3.871***	-0.0922	-1.510
	Three-arm indicator	-0.45	-1.82*	-0.395	-1.237
	Traffic signal (1 if signalised;0 otherwise)	-0.216	-1.663*	-0.177	-0.819
	SD	0.302	3.431***		
	Traffic signal (1 if un-signalised;0 otherwise)	-0.950	-5.739***	-0.894	-3.932***
	SD	0.438	3.710***		
	Two-lane number indicator	-0.222	-1.731*	-0.044	-0.228
	SD	0.526	6.132***		
	Traffic Characteristics				
	ln(AADT)	0.61	4.992***	0.655	3.526***
	Percentage of average annual daily truck traffic	0.13	7.465***	0.125	3.566***
	Dispersion parameter	13.4	2.456***	3.73	3.393***
	Observation numbers	70			
	Log-likelihood with constant only	-257.6530			
	Log-likelihood at convergence	-216.3584		-218.9279	
Within circulatory lanes	**Constant**	-1.14	1.517	-1.094	-1.244
	Geometric characteristics				
	ICD (m)	0.010	3.335***	0.010	3.255***
	Traffic signal (1 if un-signalised;0 otherwise)	-1.367	-3.864***	-0.951	-3.194***
	SD	*0.942*	*3.255****		
	Traffic Characteristics				
	Percentage of average annual daily truck traffic	0.133	2.695***	0.120	1.909*
	Dispersion parameter	1.713	3.708***	1.31	3.925***
	Observation numbers	70			
	Log-likelihood with constant only	-174.7953			
	Log-likelihood at convergence	-153.3013		-154.7943	

Table 5-10 Continued

At approaches	**Constant**	-6.712	-5.192***	-6.363	-4.582***
	Geometric characteristics				
	Lane number (1 if 2; 0 if 3)	0.041	0.265	0.19	1.102
	SD	0.589	6.102***		
	Entry width	0.058	1.808*	0.055	1.504
	Grade type (1 if grade-separated;0 if at-grade)	1.22	5.166***	1.28	5.116***
	Traffic Characteristics				
	ln(AADT)	0.55	4.007***	0.50	3.500***
	Percentage of average annual daily truck traffic	0.064	2.888***	0.068	2.612***
	Dispersion parameter	2.013	4.462***	1.407	5.352***
	Observation numbers	284			
	Log-likelihood with constant only	-533.3479			
	Log-likelihood at convergence	-493.2313		-495.1007	

* At 90% significance level ** At 95% significance level *** At 99% significance level

Table 5-11 Truck Accident Average Marginal Effects Results

Roundabout Category	Variable	NB Random-parameters model	NB Fixed-parameters model
Whole roundabouts	ICD (m)	0.041	0.04
	Circulatory roadway width (m)	-1.26	-0.88
	Three-arm indicator	-3.84	-3.79
	Two-lane indicator	-1.88	-0.43
	Traffic signal (1 if signal;0 otherwise)	-1.84	-1.69
	Traffic signal (1 if un-signal;0 otherwise)	-8.10	-8.58
	ln(AADT)	5.20	6.28
	Percentage of average annual daily truck traffic	1.14	1.20
Within circulatory	ICD (m)	0.023	0.027
	Traffic signal (1 if un-signal; 0 otherwise)	-3.1	-2.53
	Percentage of average annual daily truck traffic	0.29	0.321
At approaches	Two-lane indicator	0.057	0.297
	Entry width (m)	0.081	0.085
	Grade type (1 if grade-separated; 0 if at-grade)	1.712	1.98
	ln(AADT)	0.76	0.78
	Percentage of average annual daily truck traffic	0.090	0.11

At the approaches to the roundabouts, an improvement is seen in the log-likelihood in the random-parameters model (-493.2313) relative to the fixed-parameters model (-495.1007). According to the log-likelihood test ratio the χ^2 statistic value of 3.7388 with one degree of freedom indicates a 95% confidence that the random-parameters model is better than the fixed-parameters model. Statistically it is significant at a *p*-value of 0.05. In addition, Figure 5-8 illustrates that the predicted values of the random-parameters model are closer to the actual values relative to the fixed-parameters model. As R^2 is low, these parameters are not enough to get a good prediction, and more factors need to be considered to improve the model of truck accidents at approaches.

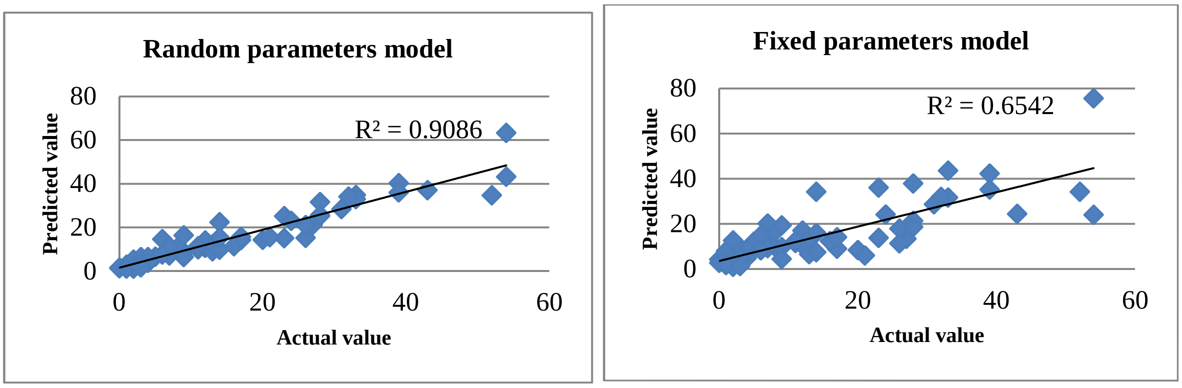


Figure 5-6 Predicted and Actual Number of Truck Accidents for Whole Roundabouts

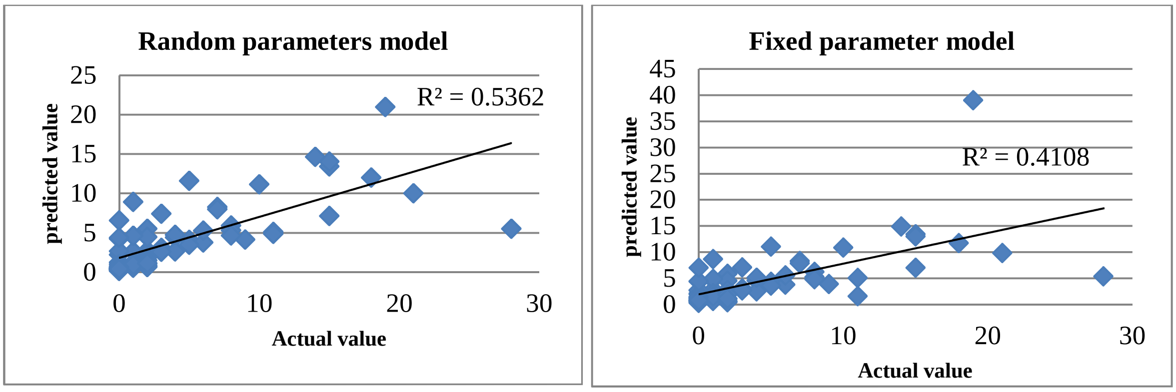


Figure 5-7 Predicted and Actual Number of Truck Accidents Within Circulatory Lanes

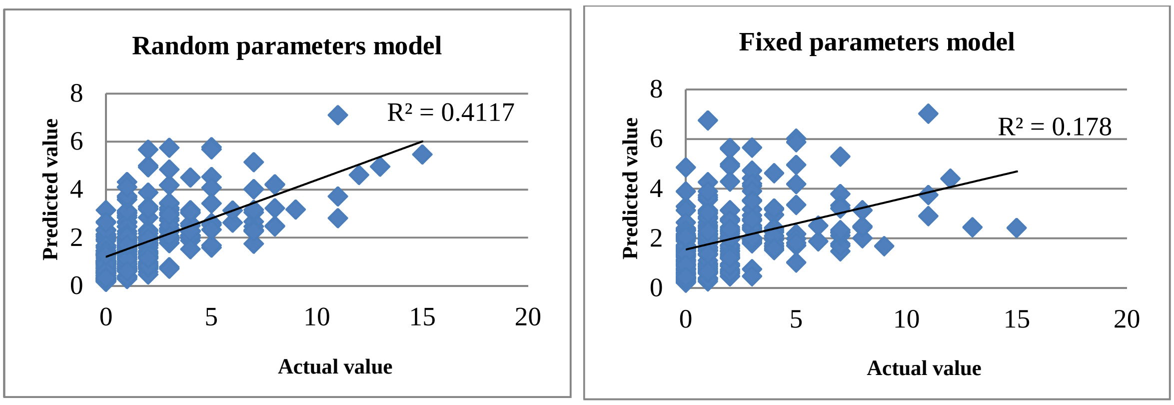


Figure 5-8 Predicted and Actual Number of Truck Accidents at Approaches

<u>For the whole roundabouts</u>, the influence of all the geometric and traffic variables except the type of grade illustrated in Table 3-9a were examined to predict truck accidents, and the following variables were found to have significant relationship with truck accidents:

- ICD,
- Circulatory roadway width,
- Three-arm roundabouts,
- AADT, and
- Truck percentage.

The following variables are related to truck accidents and their effect varied across the observations:

- Two-lane roundabouts,
- Signalised and,
- Un-signalised roundabouts.

As discussed previously, a variable is considered random when the SD of the variable is statistically different from zero, which is indicated by the *t*-statistic of the SD reported in Table 5-10.

ICD has, statistically, a highly significant positive relationship to truck accidents (*t*-statistic is significant at 99% confidence level (see Table 5-10)). 10 m increase in ICD is associated with an increase in truck accidents of 0.4 in both the random- and the fixed-parameters model (see Table 5-11). Note that higher ICD is considered unsafe for trucks in high speed areas, as stated by Arndt (1991), because this leads trucks to be unbalanced. But, Daniels et al. (2010) found that ICD has no effect on truck accidents at whole roundabouts. However, this result is small over 11-years and is considered unimportant.

Circulatory roadway width was found to have a statistically significant effect, the numbers of accidents dropping by 1.3 with a 1m increase in circulatory width, which means that a higher circulatory roadway width lowers truck accidents. This might be because higher circulatory roadway width for trucks brings more comfort to them as they circulate and lets them undertake the required manoeuvres when they are trying to leave the roundabouts safely. As Weber et al. (2009) have stated issues with trucks at roundabouts mainly concern accommodating trucks within the available geometry. They indicated that bigger roundabouts are better for trucks and other large vehicles. However, greater circulatory width may cause other types of vehicles to increase their speed, though this effect may be ameliorated by the presence of trucks, making the other drivers more careful when they are trying to make any manoeuvre while they are within the roundabouts. So it can be concluded that higher width within the circulatory provides better opportunities for manoeuvring for trucks and reduces truck accidents.

All the three-arm roundabouts had lower truck accident numbers. In the random-parameters model truck accidents at three-arm roundabouts decreased by an average of 3.8 (see Table 5-11). The three-arm roundabouts variable was found to have an insignificant effect in the fixed-parameters models, and Daniel et al. (2010) found that three arms had no effect on truck accidents. Note that Brude and Larsson (2000) state that three-arm roundabouts have fewer total accidents relative to those with four arms although Shadpour (2012) states that as number of arms increases total accidents increase because the number of conflict points increase. In this study the lower number of truck accidents within three-arm roundabouts may be a result of lower numbers of conflicts; all of them are located on at-grade location. In addition, roundabouts with lower numbers of arms provide better deflection for the driver: adequate deflection is difficult to achieve with more than three arms (DMRB TD 16/07, 2007). According to the casualty trends shown in Figure 4-19 three-arm roundabouts have lower numbers of truck accidents across the whole roundabouts (entry, circulatory, and exit). In addition, Table 4-12 illustrates that lower numbers of truck accidents occurred on three-arm roundabouts than in roundabouts with more arms. However, a higher percentage of people were killed in truck accidents at three-arm roundabouts relative to four and five-arm roundabouts and Kennedy (2007) found a higher percentage of fatalities and serious injuries recorded in accidents of all types in three-arm compared with four-arm roundabouts. This means that while three-arm roundabouts decrease truck accidents, when they occur they are more severe than at four and five-arm roundabouts. In addition, when truck accidents were related to the percentage of truck traffic (see Figure G-2 (right), Appendix G), three arms recorded lower numbers of truck accidents with the same truck traffic level compared to four, five, and six-arms roundabouts. Furthermore, Figure G-2 (left) illustrates that three arms recorded lower accidents because they constitute lower AADT.

The influence of two-lane indicator on truck accidents was varied across the whole roundabouts and 66% of the two-lane roundabouts had lower numbers of truck accidents (and 34% had higher numbers of truck accidents) than roundabouts with three lanes. The average marginal effect shown in Table 5-11 indicates that two-lane roundabouts see a decrease in the number of truck accidents by an average of 1.88. There are 39 two-lane whole roundabouts, 26 (66%) of which have lower numbers of truck accidents, with the remaining 13 (34%) seeing higher truck accident numbers. 11 out of 13 of the two-lane roundabouts that recorded higher numbers of truck accidents are grade-separated, and only two are at-grade. In addition, three of them are signalised with three un-signalised, while the other seven are partially signalised. In the 13 locations, 340 truck accidents were recorded, while in the other 26 locations only 74 truck accidents were recorded (rates of 26 and 2.8 truck accidents per roundabout, respectively). These 13 roundabouts are J10, J11, and J40 on the M6, J29, and J30 on the M1, J20, and J21 on the M5, J3 on the M27, A1237/A64, A46/B6326/A616, J15 on M40, J17 on M4, and J1 on the M54. Note in Figure 4-24 (right), and according to (Figure G-6, Appendix G), two trends with the same traffic level were identified when truck accidents are related to percentage of truck traffic based on number of lanes, and the second trend is related to the locations that recorded higher truck accidents with presence of two-lanes. When truck accidents are related to AADT, Figure G-6 (left), these locations showed higher truck accidents with higher AADT, which means AADT is the main cause of higher truck accidents at these two-lane roundabouts. For the 26 roundabouts that have a lower number of truck accidents, the majority of them (22) are un-signalised, with three of them partially signalised and only one signalised. In addition, the casualty trends shown in Figure 4-22 reveal that when looking at two-lanes across the whole roundabouts, they have lower numbers of truck accidents relative to roundabouts with three-lanes. A previous study by Daniels et al. (2010) found that number of lanes has no effect on truck accidents at whole roundabouts.

Signalised indicator influence was varied across the observations having a normal distribution with a mean of -0.216 and a SD of 0.302, this implies that 76% of the signalised roundabouts had lower numbers of truck accidents, and 24% had higher numbers of truck accidents than did partially signalised roundabouts. The average marginal effect in Table 5-11 indicates that the presence of a signalised roundabout was associated with lower numbers of truck accidents by an average of 1.84. However, the signalised roundabouts in the fixed-parameters model were found to have a statistically insignificant effect on truck accidents. 20

roundabouts as a whole are signalised, 15 of them were found to have lower rates of truck accidents, and the other five have higher rates of truck accidents. At these five locations, 192 truck accidents were recorded (a rate of 38.4 truck accidents per roundabout), while 186 accidents were recorded in the other 15 locations (a rate of 12.4 truck accidents per roundabout). The signalised locations that have higher numbers of truck accidents are all grade-separated (A1/A14, A14/A141, J28 on the M1, J10 and J40 on the M6), have high ICD, high truck traffic percentage, and four of them are five-arm roundabouts. It is possible that these factors are the reason that these five locations are associated with higher truck accidents in the presence of traffic signals.

Un-signalised indicator has a normal distribution with their effect varied across the observations having a mean of -0.950 and a SD of 0.438. This implies that 98% of the un-signalised roundabouts had lower numbers of truck accidents, and only 2% had higher numbers of truck accidents. The average marginal effect in Table 5-11 indicates that the presence of an un-signalised roundabout is associated with lower number of truck accidents by an average of 8.10. There are 28 roundabouts as a whole that are un-signalised and only one of them has a higher number of truck accidents, J30 on the M1. According to casualty results and according to model results, a roundabout that is un-signalised will have lower numbers of truck accidents and casualties (see Figure 4-17), but the highest accident fatality proportion were recorded in un-signalised roundabouts, which means that probably a lack of signalisation increases accident severity. The majority of fully signalised and un-signalised roundabouts have lower numbers of truck accidents; this means that the locations that are partially signalised are associated with higher numbers and rates of truck accidents, and indeed Table 4-12 shows that the highest numbers and rates of truck accidents occurred at partially signalised roundabouts.

The traffic related variables, AADT and percentage of trucks, were found to have a high effect on the number of truck accidents: a 1% increase in AADT increases the expected number of truck accidents by 0.61% (see Table 5-10), while a 1% increase in truck traffic increases the average number of truck accidents by 1.14% over the 11-year period (see Table 5-11). The only previous model examining truck accidents at roundabouts was carried out by Daniels et al. (2010), who found that ADT is also highly related to truck accidents. Many studies carried out on roadway segments have found that AADT and truck percentage have an influence on truck accidents. Miaou and Lum (1993), Ivan and O’Mara (1997), and Milton and Mannering (1998), for instance, have found that in roadway segments truck accidents increase with increasing AADT. Joshua and Garber (1990), and Mohamedshah et al. (1993) stated that on roadway segments as both truck percentage and AADT increases, truck accidents increase.

Within the circulatory lanes, all the traffic and geometric variables listed in Table 3-9b, except type of grade, were examined to find their influence on circulatory truck accidents, but only ICD, un-signalised circulatory lanes and the percentage of truck traffic were found to have a significant effect on circulatory truck accidents.

ICD was found to have statistically a significant effect on increasing the number of accidents (the *t*-statistic is 3.335): for a 10 m increase in ICD, circulatory truck accidents increase by an average of 0.23, as seen in Table 5-11. This effect is not high over the 11-year period and considered unimportant.

The absence of signalisation on circulatory lanes is linked to truck accidents which was varied across observations and is normally distributed with a mean of -1.367 and a SD of 0.942. This indicates that 93% of the roundabout circulatory lanes that are un-signalised had lower numbers of truck accidents (7% had higher truck accident figures). Table 5-11 reveals that roundabouts with un-signalised circulatory lanes are associated with lower numbers of truck accidents by an average of 3.1. Within the circulatory lanes, 30 roundabouts are un-signalised, 28 of them have lower numbers of truck accidents, and the other two have higher numbers of truck accidents. In the two locations that had more truck accidents, 15 accidents were recorded within the circulatory (a rate of 7.5 per circulatory), while in the other 28 locations only 19 accidents were recorded within the circulatory (a rate of 0.7 per circulatory). The two accident-prone roundabouts are J30 on the M1 and J17 on the M4. Figure G-12 (right), (Appendix G) shows that J17 on the M4 had a higher AADT compared to other un-signalised junctions within the circulatory lanes, while Figure G-12 (left) indicates that un-signalised circulatory lanes with the same truck traffic level recorded lower numbers of truck accidents compared to other traffic control type. The 28 locations comprise 12 grade-separated roundabouts, which saw 12 truck accidents within the circulatory, and 16 at-grade roundabouts, with only seven truck accidents within the circulatory lanes. This reveals that higher truck circulatory accidents are recorded in grade-separated locations.

Traffic-related factors, including the truck percentage, had a high impact on increasing the number of accidents: each 1% increase in truck percentage increased the expected number of truck accidents by 0.29%. This finding indicates that the presence of truck traffic within the circulatory affects truck accident occurrences. However, AADT was found to have an insignificant effect on truck accidents within circulatory lanes and Table 4-16 also showed that there is also not a linear relationship between truck accidents and AADT for the majority of roundabout categories. Table 4-17 indicates that truck accidents are highly related to truck traffic percentage for the majority of roundabout geometric categories.

At approaches, all the traffic and geometric variables listed in Table 3-9c were tested to find their influence on truck accidents, and the following variables were found to have be related to increasing truck accidents at approaches but their effect was fixed across the observations:

- Entry width,
- Type of grade indicator,
- AADT, and
- Truck percentage.

Unlike the total accident findings, signalisation was found to have an insignificant effect on the occurrence of truck accidents at approaches.

It was found that the data for two-lane approaches produces a random parameter relationship to truck accidents in which 53% of the observations had higher numbers of truck accident, and 47% had lower numbers. Table 5-11 shows that roundabouts that have two-lane approaches associated with lower number of truck accidents by an average of 0.057 in the random-parameters model. Two-lane approaches in the fixed-parameters model were found to have a statistically insignificant effect on truck accidents. In 172 approaches that have two-lanes, 81 (47%) of them have lower rates of truck accidents; the remaining 91 have higher rates of truck accidents. Of the 81 approaches that have lower truck accident rates, 60 of them are located on A-class roads and the others are located on M-class roads. This indicates that the majority of approaches that are two-lanes and at A-class roads are associated with lower truck accidents. Figure G-16 (left) indicates that the majority of approaches with two-lanes at the same traffic level recorded the same amount of truck accidents compared to three-lane approaches, and as AADT increases, truck accidents increased.

Entry width was found to have, statistically, a significant effect on increasing truck accidents at approaches in the random-parameters model, however this effect was found to be statistically insignificant in the fixed-parameters model. A 1 m increase in entry width increases truck accident numbers by an average of 0.08. When entry width increases, this creates a bigger space and probably allows truck drivers to enter the circulatory at a higher speed as stated by Arndt (1998) who found that the speed of entering and circulating vehicles can be reduced by decreasing entry width. However, there is another point that higher entry width is associated with higher traffic as stated by Kimber (1980). When truck accidents were normalised by percentage of truck traffic, and related to entry width (see Figure 5-9), it is clear that some locations below 10m entry width recorded lower truck accident rates, relative to the locations beyond 10m entry, while the points outlined in the circle above recorded higher normalised truck accidents rates at lower entry width, and this indicates that truck accidents at these locations are not related to truck traffic levels.

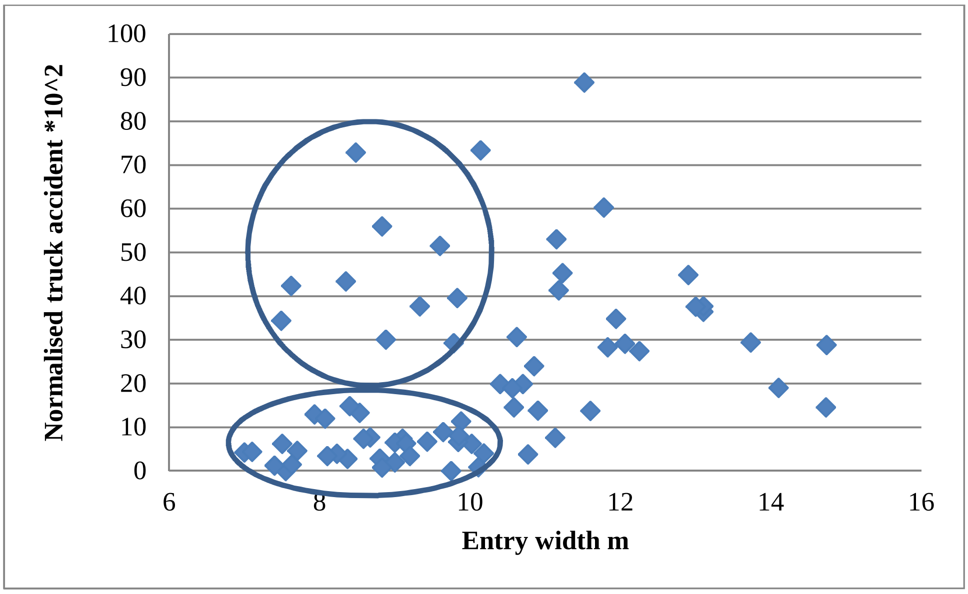


Figure 5-9 Relationship Between Normalised Truck Accident and Entry Width at Approaches

All approaches that are located at grade-separated roundabouts were found to have higher numbers of truck accidents by an average of 1.712 over the 11-year period (this rate was 1.987 in the fixed-parameters model). However, grade-separated roundabouts are considered more dangerous than at-grade roundabouts as higher accident rates are recorded and the prediction models in this chapter revealed that grade-separated roundabouts have higher accident risks than at-grade roundabouts. The probable reason for these results is that grade-separated roundabouts have high ICD, which leads to higher speeds within the circulatory lanes, they have higher AADT, higher number of arms, and the majority of them are either signalised or partially signalised, factors which are all associated with higher numbers of accidents. Note that, as for total accidents in which truck accidents are related to AADT and percentage of truck traffic (see Figure 4-31), approaches that are located at at-grade roundabouts recorded lower truck accidents compared to the approaches that are located at grade-separated roundabouts.

AADT and the percentage of truck traffic have a high influence on increasing the number of truck accidents (*t*-statistic was significant at the 99% confidence level). Table 5-11 shows that the expected number of truck accidents increases by 0.55% for each 1% increase in AADT. A 1% increase in truck traffic will increase accidents by 0.09% over the 11-year period (for the fixed-parameters model the average is 0.11%)

5.8 Truck Accident Prediction Model for Grade-Separated Roundabouts

Models based on truck accidents for grade-separated roundabouts were developed separately from at-grade roundabouts in order to compare the results to at-grade locations, and to the models that are presented in Chapter Seven for grade-separated locations based on HBIs as a dependent variable.

Tables 5-12 and 5-13 present the model estimation results and average marginal effect of truck accidents for random and fixed-parameters NB models for grade-separated locations. According to the results of log-likelihood test ratio it was found that the random-parameters model is statistically better than the fixed-parameters model; the χ^2 statistic value of 5.139 with three degrees of freedom gives 98% confidence that the random-parameters model is better than the fixed-parameters model. This implies that the model is statistically significant at a 95% significance level. As for all 70 roundabouts at grade-separated locations the random-parameters model improved the predicted number of truck accidents versus the actual value relative to the fixed-parameters model (see Figure 5-10).

Table 5-12 Truck Accident Model Estimation Results for Grade-Separated Roundabouts

Variables	NB Random-parameters model		NB Fixed-parameters model	
	coefficient	*t*-stat	coefficient	*t*-stat
Constant	-3.146	-2.417**	-4.977	-2.330**
Geometric characteristics				
ICD	0.006	3.244***	0.007	2.278**
Circulatory roadway width	-0.202	-4.966***	0.129	-1.891*
Two-lane indicator	-0.26	-2.007**	-0.06	-0.249
SD	0.628	7.311***		
Traffic signal (1 if signalised;0 otherwise)	-0.2007	-1.674*	-0.095	-0.403
SD	0.336	4.374***		
Traffic signal (1 if un-signalised;0 otherwise)	-1.24	-6.534***	-0.906	-2.994***
Traffic Characteristics				
ln(AADT)	0.59	5.105***	0.657	3.417***
Percentage of average annual daily truck traffic	0.14	9.576***	0.134	3.976***
Dispersion parameter	25.44	1.837*	4.39	2.775***
Observation numbers	51			
Log-likelihood with constant only	-196.8622			
Log-likelihood at convergence	-167.0224		-170.8567	

* At 90% significance level ** At 95% significance level *** At 99% significance level

Table 5-13 Truck Accident Average Marginal Effects Results for Grade-Separated Roundabouts

Variable	NB Random-parameters model	NB Fixed-parameters model
ICD (m)	0.07	0.09
Circulatory roadway width (m)	-2.4	-1.72
Two-lane indicator	-3.04	-0.8
Traffic signal (1 if signalised;0 otherwise)	-2.37	-1.27
Traffic signal (1 if un-signalised;0 otherwise)	-14.67	-12.1
ln(AADT)	6.91	8.77
Percentage of average annual daily truck traffic	1.66	1.79

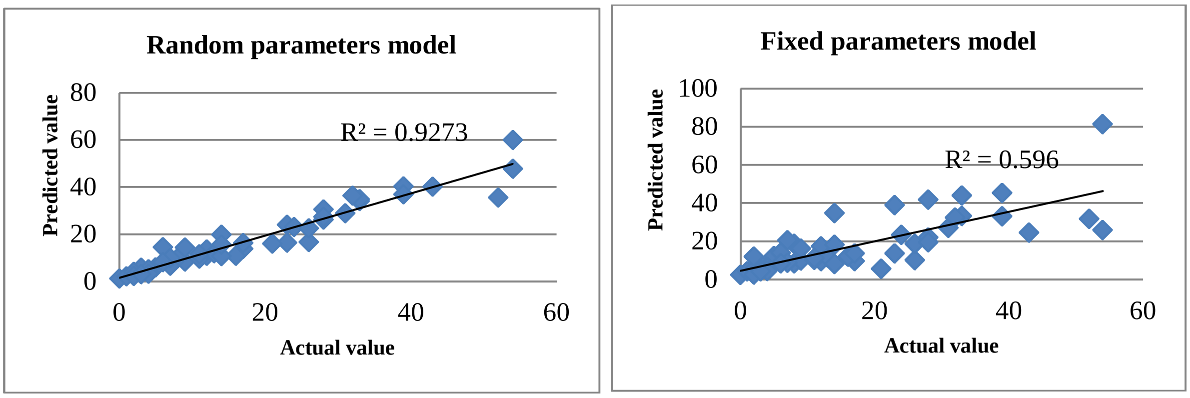


Figure 5-10 Predicted and Actual Number of Truck Accidents for Grade-Separated Roundabouts

All the geometric and traffic variables listed in Table 3-9a except the type of grade and the three-arm indicator were examined to predict truck accidents. The three-arm indicator was not examined because all grade-separated roundabouts are either four, five or six-arm roundabouts. The following variables were found to have significant effects on truck accidents at grade-separated locations:

- ICD,
- Circulatory roadway width,
- Un-signalised grade-separated roundabouts,
- AADT, and
- Truck percentage.

Un-signalised grade-separated roundabouts were found to have a fixed effect on truck accidents at grade-separated roundabouts (i.e., all un-signalised grade-separated roundabouts associated with lower truck accidents), while their effect was varied across all 70 roundabouts.

The effect of the following variables on truck accidents were found to vary across grade-separated locations:

- Two-lane grade-separated roundabouts, and
- Signalised grade-separated roundabouts.

A 10 m increase in ICD is associated with an increase in truck accidents by 0.7 in the random-parameters model (and by 0.9 for the fixed-parameters model) (see Table 5-13). Circulatory roadway width was found to have a statistically significant effect on decreasing truck accidents, by an average of 2.4 for a 1 m increase in circulatory roadway width; this rate is higher than the rate found for all 70 locations, which means that higher circulatory roadway width at grade-separated locations gives lower truck accident numbers, but has less effect at at-grade roundabouts.

The influence of the two lane indicator was varied across the grade-separated roundabouts in which 66% of the two-lane roundabouts had lower numbers of truck accidents (and 34% had higher numbers of truck accidents) than roundabouts with more than two lanes. The average marginal effect shown in Table 5-13 indicates that two-lane roundabouts decrease the number of truck accidents by an average of 3.04. Of 51 grade-separated roundabouts, 24 have two-lanes; 16 of these have lower numbers of truck accidents (a rate of 3.8 per roundabout) and the other 8 have higher numbers (a rate of 33 per roundabout). Of these eight, one of the roundabouts is signalised, one un-signalised, and the other six are partially signalised. In the other 24 locations, 11 are un-signalised, one is signalised and the other 12 are partially signalised. This indicates that partially signalised traffic control is strongly related to higher truck accident numbers in these two-lane roundabouts. Two-lane indicators were found to have an insignificant effect on truck accidents in the fixed-parameters model.

Signalised indicator influence was varied across the grade-separated roundabouts. 72.5% of the signalised roundabouts had lower numbers of truck accidents (and 27.5% had higher numbers). The average marginal effect seen in Table 5-13 indicates that the presence of signals at roundabouts decreases the number of truck accidents by an average of 2.37. Of the 51 grade-separated roundabouts, 18 are signalised, 13 of which were found to have lower numbers of truck accidents, with the other five having higher numbers. In the five locations, 192 truck accidents were recorded (a rate of 38.4 accidents/roundabout), while 175 accidents were recorded in the other 15 locations (a rate of 1.17). The locations that have higher numbers of truck accidents when they are signalised are A1/A14, A14/A141, J28 on the M1, and J10 and J40 on the M6. Each has a high ICD and high traffic volume, and four of them are five-arm roundabouts. Note that the same result was seen across all 70 roundabouts (i.e., the same signalised locations were found to have higher truck accident numbers). And it can be seen from Figure 4-20 that five-arm roundabouts are associated with higher rate of truck accidents.

Un-signalised grade-separated roundabouts were found to have a fixed effect on decreasing the number of truck accidents by an average of 14.67 (this result was 12.1 in the fixed-parameters model) over the 11-year duration. There are 13 grade-separated roundabouts that are un-signalised, only one of which has higher truck accident figures relative to the others: J30 on the M1. There is nothing obviously different about this roundabout compared with the others which would explain the results.

The traffic related variables AADT and percentage of trucks were found to have a high effect on the number of truck accidents. A 1% increase in AADT increases the expected number of truck accidents by 0.59% (see Table 5-12), while a 1% increase in truck traffic increased the average number of truck accidents by 1.66% over the 11-year period (see Table 5-13).

5.9 Truck Accident Prediction Model for At-Grade Roundabouts

This section illustrates the models that are computed for truck accidents at at-grade locations (19 roundabouts). The principal aim is to examine the influence of the geometric and traffic variables in at-grade locations on truck accidents and to compare the results with locations that are grade-separated and with the all-roundabouts models. In addition this will allow to comparison of the results to HBI models for at-grade roundabouts illustrated in Chapter Seven.

Table 5-14 illustrates the estimated model for truck accidents for at-grade roundabouts, and Table 5-15 shows the marginal effect of each parameter on truck accidents. Most of the geometric parameters illustrated in Table 3-9a were tested, however, as the majority of at-grade roundabouts have three arms, only the relationship between truck traffic and the three-arm indicator was tested (i.e. for arm indicator (1 if three; 0 if four and greater), and it was found to be insignificant. Only a fixed parameter model was identified for truck accidents at at-grade locations, because the SD of the estimated variables was not different from zero, so they all are considered fixed across the observations.

Table 5-14 Truck Accident Model Estimation Results for At-Grade Roundabouts

Variables	NB Fixed-parameters model	
	coefficient	*t*-stat
Constant	-9.22	-1.66*
Geometric characteristics		
Traffic signal (1 if un-signal;0 otherwise)	-0.87	-1.736*
Traffic Characteristics		
ln(AADT)	1.11	1.646*
Dispersion parameter	2.08	1.653*
Observations numbers	19	
Log-likelihood with constant only	-46.86	
Log-likelihood at convergence	-52.76	

* At 90% significance level

Table 5-15 Truck Accident Average Marginal Effects Results for At-Grade Roundabouts

Variable	NB Fixed-parameters model
Traffic signal (1 if un-signal;0 otherwise)	-3.51
ln(AADT)	4.50

Figure 5-11 shows that the actual values are not highly correlated to the predicted values. Note that the fact the model is fixed probably resulted in lower R^2, and more observations may reveal if the effect of all traffic and geometric variables on truck accidents are fixed or random across at-grade roundabouts.

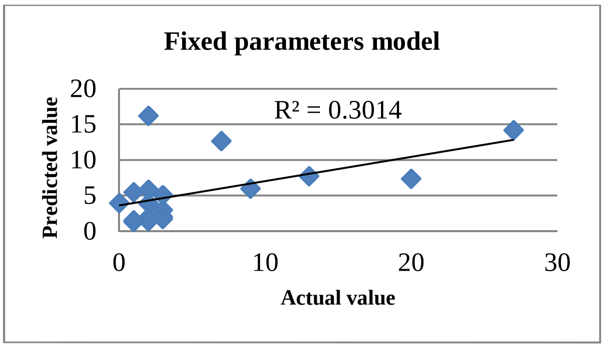


Figure 5-11 Predicted and Actual Number of Truck Accidents for At-Grade Roundabouts

Only un-signalisation as a geometric variable was found to have a significant relationship with decreasing truck accidents. According to the marginal effect shown in Table 5-15, at-grade roundabouts see a decrease in truck accidents by an average of 3.51 over the 11-year period. However, the marginal effect in un-signalised at-grade roundabouts is lower than for both all 70 and the grade-separated roundabouts.

The traffic related variable AADT was found to have a high effect on the number of truck accidents: a 1% increase in AADT increases the expected number of truck accidents by 1.11% (see Table 5-14), and this rate is higher than in grade-separated and across all 70 roundabouts. However, unlike grade-separated roundabouts, truck percentage was found to have an insignificant effect on truck accidents in at-grade roundabouts.

The resulting fixed parameters model for truck accidents at at-grade roundabouts is:

$$Truck\ Accident_{(at-grade)} = 9.9 \times 10^{-5} \times Q_w^{1.11} \times e^{-0.87\ unsignal} \quad (5\text{-}7)$$

5.10 Discussion

- As for previous studies illustrated in Table 2-5, in this study (thesis) ICD was found to have a fixed effect on accidents in a random parameters model, but previous studies have used fixed parameters models. However, previous studies did not report marginal effects, in this study when marginal affects were reported it was found that their effect is small over 11 years (2.2, 0.83 for whole roundabouts, and within circulatory total accidents, respectively, and 0.23, 0.41 for whole roundabouts, and within circulatory truck accidents, respectively). So it can be concluded that ICD effect is unimportant. However, for grade-separated roundabouts this rate was higher: 4 compared to all 70 roundabouts 2.2, indicating that ICD is associated with total accidents at grade-separated roundabouts, and is important.
- In this study using random parameters model, entry width, circulatory roadway width, and number of arms was found to have an insignificant effect on total accidents, unlike previous studies illustrated in Table 2-5. But, when previous studies have used fixed parameters models they did not account for unobserved heterogeneity so this might make this difference.
- Previous studies using fixed parameters models (Shadpour, 2012; Brude, and Larsson, 2000; Kim et al., 2013) all concluded that two-lanes are associated with higher total accidents relative to single lanes, however in this study using the random parameters model, the two-lane indicator was found to vary across observations. This indicates that not all two-lane roundabouts are associated with higher or lower accidents, and this shows the presence of unobserved heterogeneity. For instance, big roundabouts with two lanes relative to small roundabouts with two lanes may have higher numbers of accidents, probably because not all

drives records the same rate of accidents at two-lane small and big roundabouts, due to the influence of two lanes. So, this means that variables may not have fixed effect across observations and application of the random parameter method should be considered.

- In this study, signalisation, type of grade, and percentage of truck traffic were all found to have random or fixed effect in a random parameters models on accidents, however no studies included these variables in the model development and they should be considered in future work.
- In this study, for the first time relationships between truck accidents, with traffic and geometric variables were identified. AADT, percentage of truck traffic, ICD, circulatory roadway width, entry width, signalisation, number of lanes, number of legs, and type of grade were all found to be fixed or to vary across observations in random parameters models on truck accidents at roundabouts. Therefore, consideration of truck accidents with respect to traffic and geometric variables is important at roundabouts.
- At-grade roundabouts are considered safer than grade-separated roundabouts based on modelling results. This is because grade-separated roundabouts are generally big roundabouts with higher levels of traffic flow and more arms. In addition they have higher ICD, which is considered unsafe as it leads to increased speed within the circulatory lanes. Previous studies (Retting, 2006; Arndt, 1998; and Rodegerdts et al., 2007, and 2010) have found that smaller ICD improves the safety of roundabouts, as it helps maintain lower speed. In addition, in this study the majority of grade-separated roundabouts are either signalised or partially signalised and they have high rate of accidents compared to un-signalised roundabouts. As the majority of at-grade roundabouts (15 out of 19) are un-signalised, they have lower AADT and lower ICD, lower number of arms, therefore, they are considered safer than grade-separated roundabouts.

5.11 Summary and Conclusions

This chapter presents models developed for total and truck accidents. First, the extent of correlation was identified between all the geometric and traffic variables used to build the models in this study. According to the results of VIF, ICD and the type of grade indicator are highly correlated. The type of grade indicator was excluded from the models, and different models were developed for at-grade and grade-separated locations.

Comparison with previous studies using standard NB models

For the purpose of comparison with previous studies, fixed NB flow and flow-geometric models were developed and compared with the literature presented in Section 2.3.6. The major variables that influence accident occurrences were included in this study; some studies have included the influence of these variables while others included other variables, for example Maycock and Hall (1984) included entry curvature in their models, Arndt (1998), Turner et al. (2006), and Brude and Larsson (2000) included speed in their study, Šenk and Ambros (2011) included apron width, and Rodegerdts et al. (2007) included angle to next arm and approach half width. No previous study has included truck percentage, type of grade at approaches, or signalisation as variables influencing total accidents, while these effects were addressed in this study and found to have statistically a significant effect on total accidents. The flow-only model was in line with previous studies (Maycock and Hall, 1984; Guichet, 1997; Montella, 2007) and showed that AADT has a statistically significant positive effect on increasing total accidents. The flow-geometric models illustrate that some variables found to have a significant effect on accidents were also found by previous researchers to have an effect, for instance, ICD by Rodegerdts et al. (2007) and (2010), and the number of lanes at approaches by Kim et al. (2013). Entry width and circulatory roadway width in this study (thesis) were found to have an insignificant effect on total accidents. The overall fit of the fixed parameters NB model was improved when geometric variables were added to the models which supports the findings of Harper and Dunn (2005).

The random-parameters model relative to the fixed-parameters model

It can be concluded that the random-parameter models are a better tool for predicting accidents because they improved predictions compared to the fixed-parameters models. They are able to identify more significant variables, provide better fits to the data (as indicated by the relationship between predicated and actual values) and, for the random parameters identified, they can deliver information about the number of observations that was found to vary and random. The models developed to examine total accidents within circulatory lanes and at approaches, and the truck accident models developed for circulatory lanes, at approaches, and at-grade roundabouts, show a weak relationship between actual value and predicted value based on R^2 compared with the whole roundabout models. However, when they are compared with the fixed parameter model they fit the data better, as shown from the figures that relate actual number of accidents to the predicted number. For better predictability more variables are probably required, for instance, HBI, speed, driver behaviour, pavement condition, and sight lines. This indicates that telematics data could be useful for a better prediction. This will be discussed in Chapter Ten.

Table 5-16 and Table 5-17 illustrate the significant variables and their influence, fixed or random, with marginal effect, on total accidents and truck accidents, respectively.

Table 5-16 Significant Variables Influencing Total Accidents in the Random-Parameters Models

Roundabout category	Significant variable	Their effect fixed or random	Marginal value	Notes
Whole roundabout	ICD (m)	Fixed	0.22	As ICD increase total accident increases
	Un-signalised roundabout	Fixed	-26.41	Un-signalised roundabouts have fewer total accidents
	AADT	Fixed	0.40%*	As AADT increases total accident increase
	Truck %	Random	2.70%	86% of the roundabouts have higher accident numbers with higher truck percentages
Within circulatory	ICD (m)	Fixed	0.083	As ICD increases total accident numbers increases
	Un-signalised roundabout	Random	-13.57	94% of the un-signalised circulatory lanes have lower number of total accidents
	Truck%	Fixed	0.90%	As truck percentage increases total accident numbers increase within the circulatory
At approaches	Two-lane approaches	Random	1.25	66% of the two-lane approaches have higher total accidents
	Signalised approaches	Fixed	1.81	Signalised approaches have higher total accident numbers
	Approaches located on grade-separated roundabouts	Random	5.40	99.99% of grade-separated approaches have higher total accident numbers
	AADT	Fixed	0.66%*	As approach AADT increases total approach accident number increases

*regression coefficient

In a random parameters model, the influence of ICD was fixed and associated with higher total and truck accidents as illustrated in Table 5-16. Previous studies (Retting, 2006; Arndt, 1998) found that, with higher diameter, vehicle speeds increase and roundabouts become less safe. Maycock and Hall (1984) found the same effect on entering/circulating accident rates. Rodegerdts et al. (2010) found that ICD decreases vehicle deflection within exiting/circulating flows and hence increases speed and reduces roundabout safety. Note that these studies used either a linear model or a fixed parameter NB model, and they concluded their results based on statistical results, not based on marginal effects which were not reported.

Circulating roadway width as illustrated in Table 5-17 was associated with lower truck accidents (which is in line with Weber et al., 2009) while this effect was found to be statistically insignificant on total accidents, although Kim et al. (2013) found that higher circulating width is associated with lower total accidents using a fixed parameter NB model.

In this study entry width was found to be insignificantly related to total accidents in both whole roundabouts and at roundabout approaches. This contrasts with Maycock and Hall (1984) who found that total accidents when entering/circulating increases with increasing entry width. And Kim et al. (2013) found that approach total accidents increase with increasing entry width. In addition, Retting (2006) stated that roundabouts will be less safe with higher entry width. However, in this study this effect was found to be statistically significant for truck accidents and was associated with higher truck accidents at approaches.

When grade-separated roundabouts are analysed separately from at-grade roundabouts, it was found that four-arm roundabouts are associated with higher total accidents at grade-separated roundabouts, while this effect was insignificant for the complete set of 70 roundabouts. The percentage of truck traffic was found to have a fixed positive effect on total and truck accidents at grade-separated roundabouts, while this effect was found to vary across the set of 70 roundabouts, as it was also at-grade roundabouts. ICD and circulatory roadway width were found to have insignificant effect on total and truck accidents at at-grade roundabouts. The un-signalised indicator was found to be the only geometric variable related to total and truck accidents at at-grade roundabouts. Note that Truck percentage was found to have an insignificant influence on truck accidents in at-grade roundabouts; however, as the number of observations was low (19 roundabouts) further investigations are required to find the influence of the percentage of truck traffic on truck accidents for these roundabouts.

Table 5-17 Significant Variables Influencing Truck Accidents in the Random-Parameters Models

Roundabout category	Significant variable	Their effect fixed or random	Marginal value	Notes
Whole roundabout	ICD (m)	Fixed	0.04	As ICD increases truck accident numbers increases
	Circulatory roadway width (m)	Fixed	-1.30	Decreases truck accident numbers when it is higher
	Three-arm indicator	Fixed	-3.80	Three-arm roundabouts have fewer truck accidents
	Signalised roundabout	Random	-1.84	76% of the signalised roundabouts have lower truck accidents
	Un-signalised roundabout	Random	-8.10	Un-signalised roundabouts have fewer truck accidents
	Two-lane roundabouts	Random	-1.88	66% of the two-lane roundabouts have lower truck accident figures
	AADT	Fixed	0.61%*	As AADT increases truck accident increases
	Truck %	Fixed	1.14%	Roundabouts have more truck accidents with higher truck percentages
Within circulatory	ICD (m)	Fixed	0.023	As ICD increases truck accidents increase
	Un-signalised roundabout	Random	-3.10	93% of the un-signalised circulatory lanes have fewer accidents
	Truck%	Fixed	0.29%	As truck percentage increases truck accidents increase
At approaches	Two-lane approaches	Random	0.057	53% of two-lane approaches have more truck accidents
	Entry width (m)	Fixed	0.081	As entry width increases, truck accidents increase
	Grade-separated roundabouts	Fixed	1.71	Approaches located on grade-separated roundabouts have more truck accidents
	AADT	Fixed	0.54%	As approach AADT increases truck accidents increase
	Truck %	Fixed	0.090%	As truck percentage increases truck accidents increase

*regression coefficient

<u>From this chapter the following conclusions can be drawn:</u>

- It can be concluded that the influence of ICD on total and truck accidents, as well as two-lane indicator and entry width at approaches on truck accidents is small according to the marginal effect of these variables over the 11-year period.
- All the locations that have lower total accidents with higher truck percentages are at-grade roundabouts, and the majority, from this selection, are located on A5 roads. It can be concluded that smaller roundabouts with high truck percentages have fewer total accidents, and this might be because the presence of trucks in this type of roundabout leads the drivers of other vehicles to drive more carefully (i.e. not overtaking or changing lanes), as found by Milton and Mannering (1998) and Miaou (1993) even though their result was for three-lane road segments. Alternatively, A roads or at-grade roundabouts might have a greater impact on accidents rather than percentage of truck traffic.
- It is concluded that three-arm roundabouts show lower numbers of truck accidents, although the accidents are considered more severe with regard to the fatality rate.
- The fact that un-signalised roundabouts and circulatory lanes experience fewer accidents may be because roundabouts and circulatory lanes without signals are generally those carrying less traffic which, thus, has less opportunity for traffic conflicts. When accidents are related to AADT based on traffic control type, un-signalised roundabouts showed lower accident rates with lower traffic level.
- It can be concluded that at-grade roundabouts are safer than grade-separated roundabouts, as the effect of the majority of those variables varied across observations with lower numbers of accidents were found at at-grade roundabouts. The majority of un-signalised roundabouts, un-signalised circulatory lanes, and lower ICDs, lower number of arms, were all shown to have lower numbers of accidents, and all these variables are related to roundabouts that are at-grade. In addition, previous studies (Retting, 2006; Arndt, 1998; and Rodegerdts et al., 2007, and 2010) have found that smaller ICD improves the safety of the roundabouts, due to the fact that it helps maintain lower speeds on the roundabouts.

Chapter 6 Characteristics of Harsh Braking Incidents

6.1 Introduction

This chapter describes incidents of harsh braking at the selected roundabout locations. The selected roundabouts have high and low numbers of HBIs; the number of incidents differs from one roundabout to another and from one approach in a particular roundabout to another.

It is necessary to examine the similarities and differences between the incidents of harsh braking in each approach of the selected roundabouts, and it is possible to characterise them according to distance, in order to identify how close they occurred to roundabout entries; this will show how driver behaviour will change based on congestion and signalisation, and it is illustrated in the following sections. Firstly, the types of HBI are characterised by their distance from the entry line, and then the correlation between speed and driveway distance (i.e. the distance between incidents of harsh braking and the entry of the approach) is identified. Then, in order to explore how the traffic congestion affects HBI occurrence, the percentages of HBIs during peak and off-peak hours are illustrated. In addition, before building a random-parameters NB model based on HBIs and geometric and traffic variables, HBIs are linearly related to AADT and the percentage of truck traffic, based on a number of geometric variables. In the final section of this chapter, a summary and conclusion are presented.

6.2 Characterising the Type of Harsh Braking Incidents by Distance

At each approach of the roundabout there are a number of HBIs and they occur at different distances away from the entry of the approach and at different speeds. In order to characterise the type of HBIs by distance, similar to accidents, the data were divided into three groups, one is within the roundabout, one is within 100m of the entry line, and the other is more than 100 m from the entry line. As discussed in Chapter Three, 100 m was chosen because the majority of incidents occurred within this distance (see Section 3.3.3). And also this distance is chosen by DMRB TD 16/07 (2007) entry line as a measurement guide for the design of roundabouts including speed limit within 100 m from approach line, for maximum flare length, and for maximum exit kerb radius.

When numbers of HBI were counted from Google earth for approaches at 100m distance, beyond this distance and within the circulatory lanes, it was found that most of the HBIs occurred within 100 m of the entry line, although some locations have high numbers of HBIs within the circulatory lanes of the roundabouts (J21 on the M1, Gilda Brook, J16 on the M4, J2 on the M6, J11 on the M6, J19 on the M6, J15 on the M40, J3 on the M27, A4141/A14).

These locations are grade-separated and they have high ICDs, and most of them are signalised or partially signalised within the roundabout circulatory, which leads to HBIs; more details about factors influencing HBIs will be addressed in the model development section in Chapter Seven.

Some approaches of the roundabouts have HBIs at greater than 100 m distance, for instance J28 on the M1 (four-arms), south and north of J2 on the M5, west of J11 on the M6, west of J3 on the M27, west of A4141/A14, west and north of A1/A141, and north of A63/A19. These locations are very busy and big roundabouts so this might be the case for higher HBIs at approaches of these roundabouts.

Table 6-1 illustrates the comparison between total and truck accidents and HBIs within the roundabout circulatory, at less than 100 m from the entry line and at more than 100 m from the entry line. It is clear that the highest number of HBIs and total and truck accidents occurred within 100 m of the entry line: 75%, 60%, and 57%, respectively. 12% of the HBIs occurred at more than 100m away from the entry line, while only 7% of total and truck accidents occurred at distances greater than 100m from the entry line. 32% and 36% of total and truck accidents, respectively, were recorded within the roundabout circulatory, which is higher than the percentage of HBIs within the circulatory lanes (13%). This means a greater percentage of accidents were recorded within the roundabout circulatory and less at more than 100m from the entry line, compared to the HBI percentages, while a lower percentage of HBIs were recorded within the roundabout circulatory lanes and a higher percentage were recorded at distances of greater than 100m from the entry line. However, using random parameters NB models to identify the relationship between accidents and HBIs with traffic and geometric factors will clarify if similar factors influenced the occurrence of these events (see Chapter Eight for model comparison).

Table 6-1 Percentage of HBIs and Accidents Recorded in the Selected Locations at Different Distances

Type of incidents	Within 100m distance	100m away from entry line	Within roundabout circulatory
Harsh braking	75	12	13
Total accidents	60	7	32
Truck accidents	57	7	36

6.3 Relationship Between Speed and Driveway Distance from Entry Line

For the selected locations comprising at-grade and grade-separated roundabouts and all approaches that are either signalised or un-signalised, the relationship between speed and approach distance from the entry line at which the HBIs occurred was identified. Speed considered as an important safety measures for roundabouts, as a number of studies related speeds to accident occurrences (Arnd, 1998; Turner et al., 2006; Brude and Larsson, 2000) and Rodegerdts et al. (2010) states that bigger roundabouts increases speed within the circulatory lanes and makes the roundabouts less safe. In addition, Dingus et al. (2006) stated that the severity of an event increases with increasing speed.

Figures 6-1 to 6-4 present the relationship between driveway distance in metres (m) and the speed in km/h of trucks when the HBIs occurred for at-grade and grade-separated roundabouts. It can be noticed that two trends were recorded, one is for those HBIs that occurred at below 20 km/h, and the other is for HBIs with a speed greater than 20 km/h. Approaches with HBIs at lower speeds were found to have lower numbers of HBIs compared to approaches that have HBIs recorded at higher speeds.

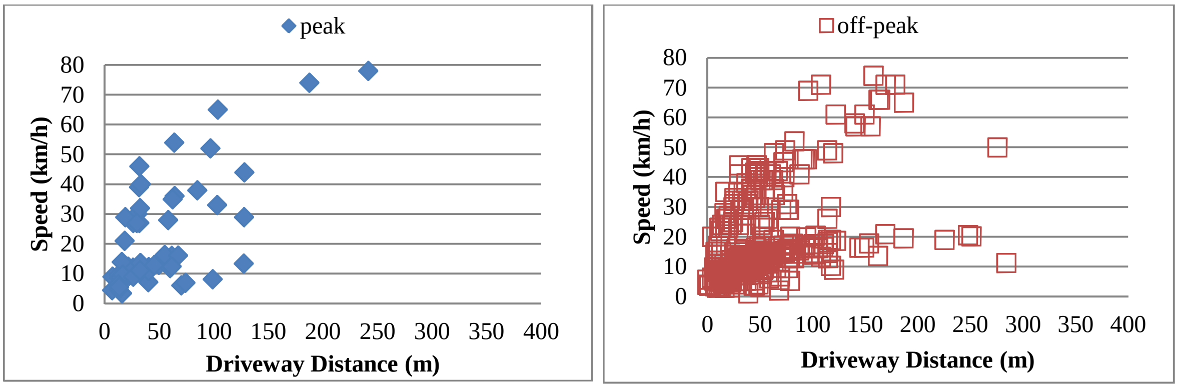


Figure 6-1 Two Pattern Trend Between Driveway Distance and Speed of Trucks for Signalised Approaches that are Located on At-Grade Approaches

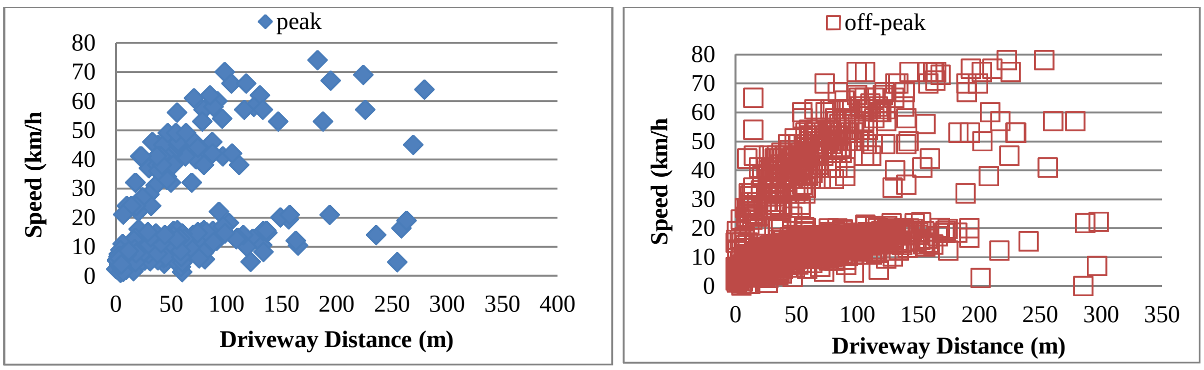


Figure 6-2 Two Pattern Trend Between Driveway Distance and Speed of Trucks for Un-Signalised Approaches that are Located on At-Grade Approaches

It can be seen that the number of approach HBIs in un-signalised at-grade roundabouts is higher than the number of HBIs in signalised at-grade roundabouts, because a higher number of approaches that are at-grade are un-signalised (62 relative to 11 approaches). However, the rate of HBI per approach in signalised at-grade approaches is higher than un-signalised at-grade approaches (42.3 relative to 28, respectively).

In addition, more approaches that are grade-separated are signalised (131 approaches) when compared with un-signalised grade-separated approaches (80 approaches). However, the rate of HBIs per signalised grade-separated approach is much higher than un-signalised grade-separated approaches (40.6 relative to 16.5, respectively). This indicates that signalised at-grade and signalised grade-separated approaches recorded higher numbers of HBIs. More detail about signalisation's influence on HBIs will be given in the next chapter.

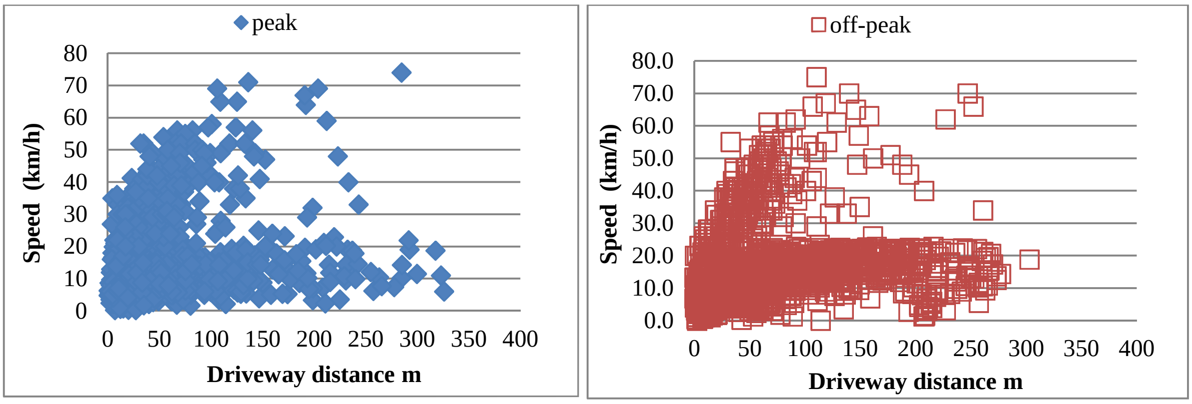


Figure 6-3 Two Pattern Trend Between Driveway Distance and Speed of Trucks for Signalised Approaches that are Located on Grade-Separated Roundabouts

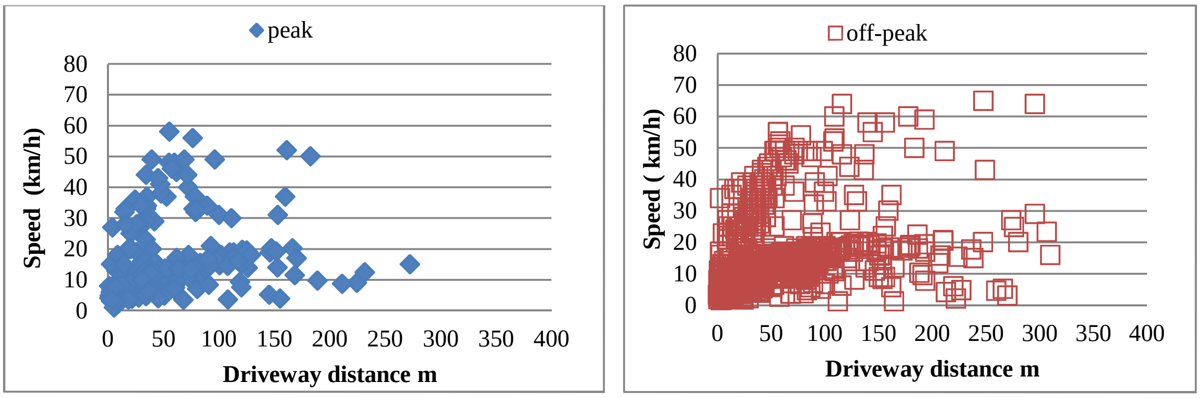


Figure 6-4 Two Pattern Trend Between Driveway Distance and Speed of Trucks for Un-Signalised Approaches that are Located on Grade-Separated Roundabouts

Note that for the majority of approaches located at at-grade and at grade-separated roundabouts (signalised and un-signalised), that have speeds between 0-20 km/h, HBIs occurred at a closer distance to entry line than those HBIs that occurred at greater distances and higher speeds. This means that as trucks reach the entry line their speed decreases, which is in line with the study of Qian et al (2015) who stated that drivers of passenger cars reduce their speed from 48 km/h to 21-30 km/h and to 11-20km/h while they are entering the roundabout.

Considering individual approaches, some have a different pattern (as shown in Figure 6-5). It is clear that there is a one pattern trend between speed and distance from the entry line. All the approaches (11 approaches) that have a one pattern trend are un-signalised, have lower numbers of HBIs, most of them are at at-grade roundabouts, and most HBIs occurred at lower speeds (0-20 km/h). In addition, these HBIs happened during a consistent time period, for instance, during the morning period or during the evening period, while for approaches that have a two pattern trend, they occurred during different times of the day.

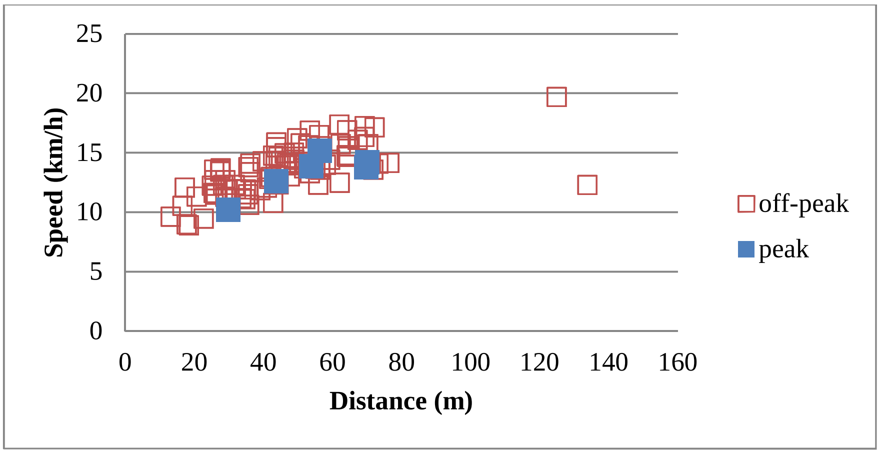


Figure 6-5 One Pattern Trend Between Driveway Distance and Speed of Trucks for the East Direction of Lodge Lane Roundabout

To characterise the type of braking HBI by the time of day, in order to identify if traffic congestion increases the occurrence of HBIs, the percentages of trucks braking during peak and off-peak hours were identified. Table 6-2 shows the percentage of truck braking incidents during peak and off-peak hours for the selected at-grade and grade-separated roundabouts. Based on DFT (2015), the morning peak started at 7:00am and ended at 9:00am, and the evening peak started at 4:00pm and ended at 6:00pm, meaning that there are 4 peak hours and 20 off-peak hours. Dividing the percentage of HBIs during peak hours by the number of peak hours (see Table 6-2) shows that the rate of HBIs during the peak hours on signalised and un-signalised at-grade roundabouts are equal to the rate of truck HBIs during off-peak hours. This means that the majority of truck drivers are driving during off-peak times as there are more off-peak hours, but this point does not lead to lower numbers of HBIs, as the same rate of HBIs are recorded during off-peak hours compared to peak-hours at at-grade roundabouts. In addition, signalisation (signalised and un-signalised approaches) has no effect on these rates. For signalised and un-signalised grade-separated roundabouts, the percentage of HBIs divided by the number of peak and off-peak hours reveals that there are higher rates of truck HBIs during peak periods; and this rate was higher by only 0.5 for un-signalised grade-separated approaches, the probable reason for this is that grade-separated roundabouts have higher traffic levels and different geometric designs. For all types of roundabout categories, the rate of HBIs is high in peak hours, i.e. when traffic is congested. According to previous studies, Lee et al. (2007) have found that 45% and 50% of near-miss accidents and HBIs, respectively, were recorded in congested traffic. In addition, Klauer et al. (2009) found that in traffic congestion while speed is restrained, drivers are more involved in serious driving behaviour than the situation of low flow and unrestrained speed.

Table 6-2 Percentage of Truck HBIs During Peak and Off-Peak Hours

Grade type	Traffic control type	% of HBI in peak period	% of HBI in off-peak period	% of peak per peak hour (rate)	% of off-peak per off-peak hour (rate)
At grade	signal	16	84	4	4
At grade	un-signal	15	85	4	4
Grade separated	signal	21	79	5	4
Grade separated	un-signal	22	78	5.5	4

6.4 Characteristics of Harsh Braking Incidents with Traffic Characteristics

In this section the relationships between HBIs and each of AADT, the percentage of truck traffic, at the different geometric layouts of the selected roundabouts are presented. The principal aim of this section is to explore how HBI are related to AADT and percentage of truck traffic with respect to number of arms, number of lanes, traffic control, and type of grade in order to identify the similarities or differences between these geometric factors at whole roundabouts, within circulatory lanes, and at roundabout approaches. This will help obtain the main variables at the selected roundabout categories to be included in the model which is presented in next Chapter. The following subsections illustrate the ANOVA results of the relationships between HBIs with traffic characteristics for each roundabout category (see Appendix H for detailed figures). Note that the outliers discussed in this section were identified using visual inspection and they were included in the models presented in the next chapter.

6.4.1 Characterisation of Harsh Braking Incidents at Whole Roundabouts

Table 6-3 illustrates the number of HBIs based on the geometric factors that are considered in this thesis. Based on the number of arms, similar to total and truck accidents five-arm roundabouts showed the highest rate of HBIs. Unlike, total and truck accidents, six-arm roundabouts show the lowest rate of HBIs. Probably having a higher number of six-arm roundabouts might give a result different from that obtained with seven observations of six-arm roundabouts. The majority of the selected three-arm roundabouts have a high percentage of truck traffic, and as a result a higher rate of HBIs was identified in three-arm roundabouts compared to those with six. Whole roundabouts see higher rates of HBIs with three lanes; this reveals that as the number of lanes increases the number of HBIs increases, and the same result was identified for total and truck accidents. Lower rates of HBIs were recorded in un-signalised roundabouts, followed by signalised and partially signalised roundabouts. For total and truck accidents partially signalised roundabouts recorded higher numbers of accidents followed by signalised and un-signalised roundabouts; but the rate of accidents in partially signalised roundabouts was close to the rate of accidents at signalised roundabouts. In addition, higher rates of HBIs were recorded in grade-separated locations relative to at-grade locations. A similar result was identified for total and truck accidents, but the rate of accidents for grade-separated was much higher than the rate of accidents at at-grade roundabouts (see Table 4-12).

Table 6-3 Harsh Braking Numbers and Rates According to Different Geometric Factors for Whole Roundabouts (Entry and Circulatory)

Factor	Factor category	Number in factor category	HBI	
			No.	Rate (HBI per junction)
Number of arms	Three-arms	12	1262	105.2
	Four-arms	39	5312	136.2
	Five-arms	12	3524	293.7
	Six-arms	7	586	83.7
Number of lanes	Two-lane	39	4575	117.3
	Three-lane	31	6109	197.1
Signalisation	Signalised	20	4288	214.4
	Un-signalised	28	2667	95.3
	Partially signalised	22	3729	169.5
Type of grade	Grade-separated	51	8128	159.4
	At-grade	19	2556	134.5

HBIs are correlated with AADT and truck percentage with respect to each of lane number, arm number, signalisation, and type of grade. In order to examine how HBIs relate to AADT and the percentage of truck traffic in different roundabout types, a linear relationship was identified between them, with the results illustrated in Table 6-4. The results show how HBIs are related to AADT and the percentage of truck traffic according to each roundabout category, and show that based on traffic characteristics the characteristics of each roundabout category were determinate.

Table 6-4 ANOVA Results for HBIs with AADT Based on Different Roundabout Geometric Factors for Whole Roundabouts

Roundabout category/factor	HBI with AADT			HBI with truck%		
	R^2	*p*-value	Sig	R^2	*p*-value	Sig
Three-arm	0.28	0.076	yes	0.01	0.72	no
Four-arm	0.07	0.105	no	0.30	0.000	yes
Five-arm	0.30	0.066	yes	0.05	0.495	no
Six-arm	0.21	0.299	no	0.16	0.369	no
Two-lane	0.19	0.005	yes	0.18	0.006	yes
Three-lane	0.15	0.034	yes	0.06	0.192	no
Signalised	0.03	0.458	no	0.06	0.293	no
Un-signalised	0.06	0.215	no	0.11	0.018	yes
Partially signalised	0.52	0.000	yes	0.19	0.132	no
Grade-separated	0.21	0.001	yes	0.01	0.024	yes
At-grade	0.44	0.002	yes	0.08	0.246	no

Regarding the number of arms, Table 6-4 indicates that no statistically significant linear effect of variation in AADT on the variability of HBIs was detected for four-arm and six-arm roundabouts. The four outlier points in Figure 6-6 are four-arm roundabouts in which higher numbers of HBIs were seen relative to the other points with the same levels of AADT. These locations are: Gilda Brook roundabout, which is located on the M602 and J18 on the M4, both are signalised and grade-separated; the A14/A141 roundabout, which is one of the locations that recorded high numbers of HBIs because of a high percentage of truck traffic (22%) and because it is grade-separated; the Walsall road roundabout located on the A5, which recorded high numbers of HBIs with lower AADT, the probable reason being that this roundabout has a high percentage of truck traffic (11%). The other points that recorded lower number of HBIs with the same level of AADT were found to have a lower percentage of truck traffic, regarding the geometric measurements they are similar to the other locations that recorded higher numbers of HBIs.

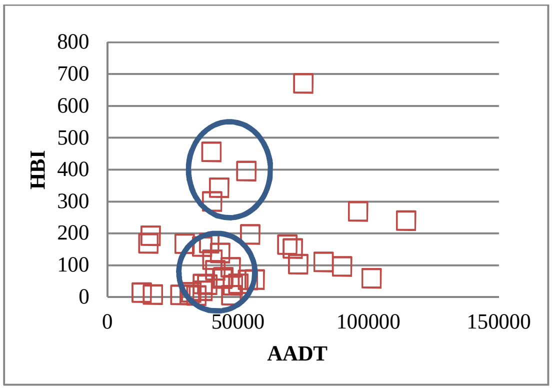


Figure 6-6 Relationship Between HBIs and AADT in Four-Arm Roundabouts

When HBIs are related to the percentage of truck traffic, statistically a significant linear relationship was identified between them in four-arm roundabouts, while no statistically significant relationship was found in three, five, and six-arm roundabouts.

Figure 6-7 indicates that two three-arm roundabouts recorded a high number of HBIs with the same level of traffic relative to the three-arm roundabouts that recorded lower numbers, these are the Bromley Heath and A63/A19 roundabouts. Note that the Bromley Heath roundabout is a three-arm signalised roundabout and has three-lanes; however, the truck percentage is not high at this junction, indicating that the number of lanes and signalisation could influence these HBIs. The A63/A19 roundabout was found to be un-signalised and recorded high HBIs with a lower percentage of truck traffic, it is noted that the average entry width in this junction is high (11m). The outlier that recorded low HBIs (11) with a high truck percentage (12%) is the A5/A5/A361 roundabout, which is un-signalised (see the outlier in the orange circle in Figure 6-7). It should be noted that the majority of A5 roads have a high percentage of truck traffic, but this roundabout recorded lower HBIs relative to others.

The two outlier five-arm roundabouts in Figure 6-7 are J2 on the M6 and J16 on the M4. These two junctions recorded high numbers of HBIs with a low percentage of truck traffic (3%). One of the arms of J2 on the M6 is the M69, and AADT at this junction is very high and it is partially signalised, and these are the possible reasons for these high number of HBIs. J16 on the M4 is a signalised five-arm roundabout with high AADT, which may cause the high number of HBIs.

The six-arm roundabout outlier in Figure 6-7 has a high number of HBIs with a low percentage of truck traffic. This junction is partially signalised and has high AADT, which may be considered as causes of this high number. These outliers show that the percentage of truck traffic is not always the cause of HBIs, and AADT, geometric factors and signalisation can all be considered as related to of HBIs. More detail is presented in Chapter Seven when discussing the HBI models.

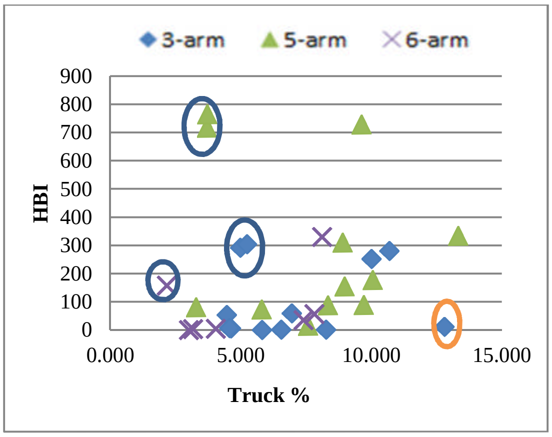


Figure 6-7 Relationship Between HBIs and Percentage of Truck Traffic for Three, Five and Six-Arm Roundabouts

When HBIs were related to AADT with respect to the number of lanes, it was found that statistically HBIs increase with increasing AADT in a linear relationship in two and three-lane roundabouts. For two-lane roundabouts, statistically and from a practical point of view HBIs are related to the percentage of truck traffic in a linear relationship, but this relationship becomes insignificant in three-lane roundabouts (see Table 6-4). The majority of the roundabouts see increased HBIs with increasing percentages of truck traffic, except the three outlier roundabouts in Figure 6-8. These are J2 on the M6, J16 on the M4 and Gilda Brook roundabout, and as discussed previously these points have high AADT, high HBI numbers, and a low percentage of truck traffic.

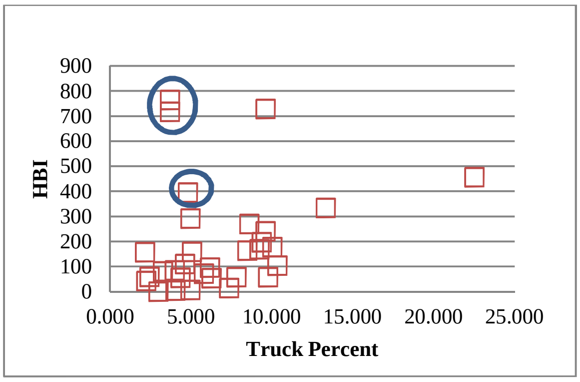


Figure 6-8 Relationship Between HBIs and Percentage of Truck Traffic in Three-Lane Roundabouts

The linear relationship between HBIs and AADT with respect to traffic control (Table 6-4) reveals that the two are not related to each other statistically in a linear relationship at signalised or un-signalised roundabouts. However, a strong statistical linear relationship was identified between HBIs and AADT in partially signalised roundabouts. Moreover, from a practical point of view R^2 of 0.52 in partially signalised roundabouts indicating that increasing AADT has high impact on increasing HBIs. The relationship between HBIs and the percentage of truck traffic becomes insignificant at partially signalised and signalised roundabouts, while in un-signalised roundabouts 11% of the total variation in HBIs can be explained by the variation of truck traffic percentage.

In grade-separated roundabouts, statistically significant linear relationships were identified between HBIs and AADT (see Table 6-4). And statistically significant linear relationships were identified between HBIs and percentage of truck traffic, however, with R^2 of 0.01 considered negligible from a practical point of view, thus percentage of truck traffic increase HBIs but by a small amount if the relationship is considered linearly. In at-grade roundabouts statistically and practically a strong significant linear relationship was only identified between HBIs and AADT: there is no significant relationship between HBIs and the percentage of truck traffic in at-grade roundabouts. The two at-grade outliers in Figure 6-9 which recorded high numbers of HBIs compared with the other roundabouts circled at the same percentage of truck traffic are Bromley Heath roundabout and the A63/A19 roundabout. As discussed earlier, Bromley Heath is a three-lane signalised roundabout, which probably is the cause of these high numbers of HBIs, and the A63/A19 roundabout has a high average entry width. The other two outliers that recorded lower HBIs with the same level of truck traffic are Dramway, and A1246/A63 roundabouts, which are two-lane, un-signalised roundabouts. Note that the points in the orange circle in Figure 6-9 show locations with high percentages of truck traffic, and it is clear that the number of HBIs in these locations increases with increasing percentage of truck traffic. It was found that the majority of them are un-signalised roundabouts. This means un-signalised roundabouts with higher truck percentages make at-grade roundabouts less safe.

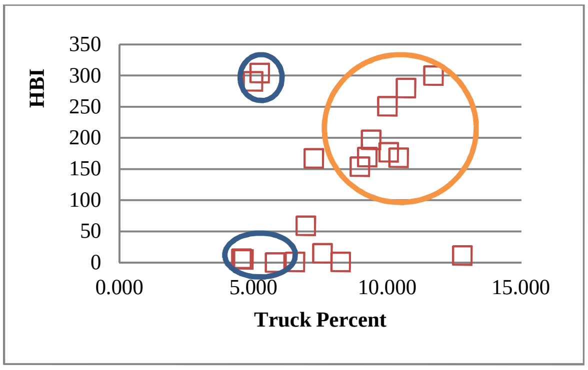


Figure 6-9 Relationship Between HBIs and Percentage of Truck Traffic in At-Grade Roundabouts

Thus for whole roundabouts, for the majority of geometric factors HBIs was related to AADT linearly rather than to percentage of truck traffic, in addition for partially signalised roundabouts and for at-grade roundabouts about 50% of the variation in HBIs can be explained by AADT. In addition, each of the geometric characteristics was found to have an influence on these HBIs when there was not a relationship between traffic and HBIs.

6.4.2 Characterisation of Harsh Braking Incidents Within Circulatory Lanes

A lower percentage of HBIs were recorded within the circulatory lanes (13%). The principal aim of this section is to relate HBIs within the circulatory lanes to AADT and the percentage of truck traffic with respect to lane number, traffic control, and type of grade, using linear relationships. It is necessary to examine the characterisation of HBIs with respect to traffic variables, before building a model based on all the variables together. This will enable explanation of how the traffic variable influences HBIs at the selected roundabouts with respect to different geometric characteristics.

Table 6-5 shows the number of HBIs with respect to number of lanes, traffic control, and type of grade. Within the circulatory lanes, higher numbers and rate of HBIs are recorded with three lanes than with two. As regards traffic control, as with truck accidents within the circulatory lanes (see Section 4.5.2), higher numbers, and rates of HBIs happened in signalised, followed by partially signalised circulatory lanes. The rate of HBI in un-signalised circulatory lanes is very low compared to signalised and partially signalised circulatory lanes. Lower numbers of total and truck accidents occurred in un-signalised circulatory lanes. And on average the rate of HBIs are much higher in grade-separated circulatory lanes than in at-grade circulatory.

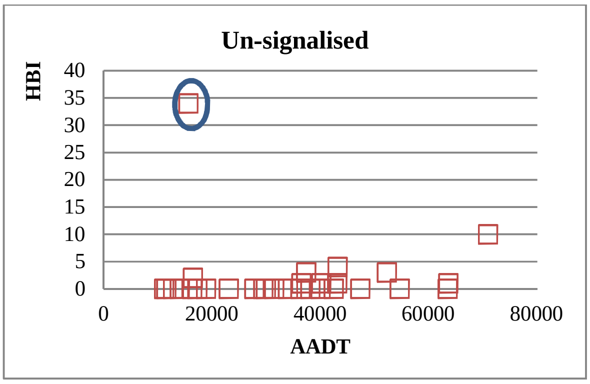
Table 6-5 HBI Numbers and Rates According to Different Geometric Factors Within Circulatory Lanes

Factor	Factor category	Number of factor category	HBI	
			No.	Rate (HBI/junction)
Number of lanes	Two-lane	40	249	6.2
	Three-lane	30	1078	35.9
Signalisation	Signalised	21	856	40.8
	Un-signalised	30	60	2.0
	Partially signalised	19	411	21.6
Type of grade	Grade-separated	51	1278	25.1
	At-grade	19	49	2.6

Table 6-6 illustrates the ANOVA results for HBIs when they are related to AADT and the percentage of truck traffic with respect to different types of roundabout geometrics. Within the circulatory lanes, Table 6-6 illustrates that HBIs are related statistically to AADT in two-lane, three-lane, signalised, and grade-separated circulatory systems, moreover, as for whole roundabouts, there is a strong linear relationship between HBIs and AADT in partially signalised roundabouts. While un-signalised circulatory lanes and circulatory lanes located at at-grade roundabouts show no statistical linear relationship between HBIs and AADT. Note that Table 6-5 illustrates that the rate of HBIs is low within the circulatory lanes especially in un-signalised circulatory lanes (2.0) and in those located in at-grade roundabouts (2.6). A lower number of HBIs were recorded with different levels of traffic in un-signalised circulatory lanes, and in those located in at-grade roundabouts (see Figure 6-10). The roundabout outlier in Figure 6-10 which recorded a higher number of HBIs relative to other roundabouts is the A19/A645 junction; it was found that this roundabout had a high percentage of truck traffic (10%).

Table 6-6 ANOVA Results for HBIs with AADT and Percentage of Truck Traffic Based on Different Geometric Factors Within Roundabout Circulatory Lanes

Factor	HBI with AADT			HBI with truck%		
	R^2	*p*-value	Sig	R^2	*p*-value	Sig
Two-lane	0.26	0.001	yes	0.01	0.048	yes
Three-lane	0.17	0.022	yes	$6*10^{-6}$	0.966	no
Signalised	0.16	0.070	yes	$8*10^{-7}$	0.998	no
Un-signalised	0.0021	0.810	no	0.04	0.297	no
Partially signalised	0.52	0.000	yes	0.28	0.018	yes
Grade-separated	0.25	0.000	yes	0.02	0.280	no
At-grade	0.02	0.532	no	0.045	0.379	no



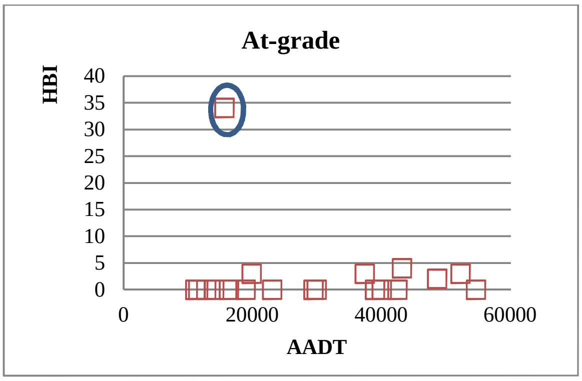


Figure 6-10 Relationship Between HBIs and AADT in Un-Signalised Circulatory Lanes (left) and in Circulatory Lanes Located in At-Grade Roundabouts (right)

When the outlier from Figure 6-10 for both un-signalised and at-grade circulatory lanes was removed from the data and re-analysed, it was found that statistically there is a significant linear relationship between HBI and AADT in un-signalised circulatory lanes (F (1, 27) = 8.627, p-value<0.01) and for un-signalised circulatory lanes (F (1, 16) = 3.112, p-value<0.10). In addition, R^2 of 0.24 for un-signalised circulatory lanes and with R^2 of 0.16 for at-grade circulatory lanes is statistically significant and indicates that as AADT increases HBI increases.

When HBIs were related to the percentage of truck traffic, statistically a significant linear relationship was found between the two in only two-lane and partially signalised circulatory lanes (see Table 6-6). However, for two-lane roundabouts R^2 of 0.01 is considered negligible from a practical point of view, thus percentage of truck traffic increase HBIs but only by a small amount. Conversely, in partially signalised roundabouts increasing the percentage of truck traffic has a high impact on increasing HBIs within circulatory lanes.

From this linear relationship it is clear that within circulatory lanes, the occurrence of HBIs is more related to AADT rather than percentage of truck traffic for all geometric factors included in this study.

6.4.3 Characterisation of Harsh Braking Incidents at Approaches

Table 6-7 shows the number of HBIs with respect to number of lanes, traffic control, and type of grade. In this study 87% of HBIs were recorded at approaches. A high rate of HBIs was recorded in three-lane relative to two-lane approaches, in addition, the rate of HBI in signalised approaches is double that of the un-signalised approaches. In contrast to total and truck accidents, the rate of HBIs in approaches that are located in grade-separated roundabouts is nearly similar to the rate of HBIs in approaches that are located at-grade.

Table 6-7 HBI Numbers According to Different Geometric Factors at Approaches

Factor	Factor category	Number of factor category	HBI	
			No.	Rate
Number of lanes	Two-lane	172	3765	21.9
	Three-lane	112	5075	45.3
Signalisation	Signalised	142	5790	40.8
	Un-signalised	142	3050	21.5
Type of grade	Grade-separated	211	6645	31.5
	At-grade	73	2195	30.1

In this section, HBIs at approaches are related to AADT and truck percentage with respect to number of lanes, traffic control, and type of grade, in a linear relationship. The aim is to explore how HBIs are related to AADT and percentage of truck traffic, based on different geometric category at approaches, in order to identify the similarity or differences between geometric categories at approaches. This will help obtain the main variables at approaches to be included in the model which is presented in Chapter Seven.

Table 6-8 illustrates the ANOVA results between HBIs and traffic characteristics at different types of roundabout approaches. It is clear that a statistical linear relationship was found between HBIs based on all approach categories, which indicates that as AADT increases at approaches, HBI also increase. However, when HBIs are related to AADT in two-lane, three-lane, and signalised approaches with this low R^2 their effect is considered negligible from a practical point of view. A better R^2 was identified for un-signalised approaches, and for approaches that are located in grade-separated roundabouts, which is expected since AADT increase HBI increases, and in approaches that are located in at-grade roundabouts increasing AADT have high impact on increasing HBIs.

When relating HBIs with percentage of truck traffic, a statistical linear relationship was found between HBIs based on all approach categories, as percentage of truck traffic increases HBIs increases. However, from a practical point of view with the low R^2 for all approach categories this effect is considered negligible and they increase HBIs by only a small amount.

Table 6-8 ANOVA Results for HBIs with AADT and Percentage of Truck Traffic at Roundabout Approaches Based on Different Roundabout Geometric Characteristics

Factor	HBI with AADT			HBI with truck %		
	R^2	*p*-value	Sig	R^2	*p*-value	Sig
Two-lane	0.08	0.000	yes	0.06	0.002	yes
Three-lane	0.08	0.002	yes	0.07	0.004	yes
Signalised	0.08	0.001	yes	0.07	0.002	yes
Un-signalised	0.13	0.000	yes	0.07	0.002	yes
Grade-separated	0.1	0.000	yes	0.07	0.000	yes
At-grade	0.31	0.000	yes	0.07	0.031	yes

Therefore, as for total and truck accidents at approaches because of large variation in AADT and HBIs, very low R^2 were acquired. Probably because there are a number of approaches having zero or one HBI with the same level of traffic compared to other approaches with higher numbers of HBIs with a lower level of AADT. This indicates that the relationship between accident numbers and traffic variables is not linear. For this reason, an NB regression model will clarify the influence of all geometric and traffic variables together on total and truck accidents, as illustrated in the total and truck accident model development in Chapter Seven.

6.5 Summary and Conclusions

In summary, while most of the truck HBIs occurred within 100 m of the entry line on roundabout approaches, some locations have high numbers of HBIs beyond 100 m distance. These locations are on motorways and have high ICDs and they are busy roundabouts, and the locations that have high HBIs within roundabout circulatory lanes are signalised. The results of accidents characterised by distance were compared to HBIs characterised by distance, and the percentage of total and truck accidents within roundabout circulatory lanes is much higher than the percentage of HBIs within the roundabout circulatory lanes.

Two trends were identified when the speed of trucks at the time of HBIs was correlated to approach driveway distance. The trends were recorded at lower speeds (between 0-20 km/h) and higher speeds (greater than 20 km/h). The majority of trucks that braked at lower speeds while entering the roundabout, which is in line with the study of Qian et al (2015) for passenger cars. Traffic control type and type of grade were found to have an impact on the occurrence of HBIs, and their statistical effects are presented in Chapter Seven. A group of individual approaches demonstrate a one pattern trend between speed and distance. All these approaches are un-signalised, have lower numbers of HBIs, most of them are at-grade roundabouts, most of the HBIs occurred at lower speeds (0-20 km/h), and the time period when these HBIs occurred is different than for those that show a two pattern trend.

For signalised and un-signalised at-grade roundabouts, the same rate of HBIs occurs during the peak and off-peak period. However, signalised and un-signalised grade-separated roundabouts show a higher rate of truck HBIs during peak periods. This indicates that traffic congestion increases the occurrence of HBIs as found by Lee et al. (2007), and Klauer et al. (2009), who found that the severity of events increases in congested traffic.

A lower percentage of HBIs were recorded within the circulatory lanes (13%), especially in un-signalised and at-grade roundabouts. This may imply that these types of roundabout circulatory can be considered safer than signalised, partially signalised, or grade-separated roundabout circulatory lanes. But based on accident trends in Chapter Four, un-signalised roundabouts have a higher fatality percentage compared to signalised and partially signalised roundabouts. However, the random-parameters NB model will identify these effects, which will give a final conclusion if the same effects were identified.

Comparing the ANOVA results for accidents (total and truck) and HBIs, it was found that the three events shows a linear relationship to AADT with respect to number of lanes, type of grades and at partially signalised roundabouts. However, not all the geometric characteristics similarly showed a linear relationship of the three events to percentage of truck traffic. However, modelling results will clarify these effects.

From the ANOVA results, it can be concluded that grade-separated roundabouts and at-grade roundabouts show different HBI trends for whole roundabouts, and within circulatory lanes. For this reason, it is necessary to build a model for each type of grade based on traffic and geometric characteristics, and the next chapter illustrates this model. In addition, un-signalised and two-lane roundabouts showed a different trend from three-lane and signalised and partially signalised roundabouts, and it is necessary to examine the effect of these variables on HBIs using a NB distribution; more details are illustrated in Chapter Seven. The number of arms has also shown different trends, and their effect will be identified and illustrated in the next chapter.

Chapter 7 Harsh Braking Incident Prediction Models

7.1 Overview

The principal aim of this research is to analyse potentially unsafe truck driving conditions from HBIs that may have the chance to result in accidents. For this purpose, a number of geometric and traffic variables were selected in order to identify how these variables affects the occurrence of HBIs, using random and fixed-parameters NB count data models for whole roundabouts, within circulatory lanes, and at approaches, and these are illustrated in the following sections. In addition, HBI models for grade-separated and at-grade locations were identified and are presented in this chapter. A comparison to accident prediction models will reveal whether the impact of the identified variables is the same for total and truck accidents and HBIs, which might mean that these models can provide additional information for roundabout safety in addition to the truck accident and total accident models, in order to prioritize safety schemes, and this comparison is made in Chapter Eight. These HBIs are far more numerous than accidents, and could potentially provide information over a much shorter timescale.

7.2 Harsh Braking Incident Model Results

As for total and truck accident models, models for HBIs were estimated based on whole roundabouts (approaches and circulatory), within circulatory lanes, and at approaches to the roundabouts. Table 7-1 presents the results of the estimated random and fixed-parameters NB models. Table 7-2 illustrates that the average marginal effects results and it is clear that the results can be quite different for the two types of model.

The results show that for **whole roundabouts**, the log-likelihood at convergence for the random-parameters model is better compared to the fixed-parameters model; and according to its log-likelihood test ratio, the χ^2 statistic value Eq. (3-12) of 8.63 with three degrees of freedom gives 97% confidence that the random-parameters model is statistically more significant. In addition, Figure 7-1 illustrates a better overall fit was identified when actual values are related to predicted values for the random-parameters model relative to the fixed-parameters model.

Table 7-1 HBI Model Estimation Results

Roundabout category	Variables	NB Random-parameters model		NB Fixed-parameters model	
		Coefficient	*t*-stat	coefficient	*t*-stat
Whole roundabout	**Constant**	-11.36	-4.80***	-8.40	-2.351**
	Geometric characteristics				
	Arm number (1 if 3 arm;0 otherwise)	0.064	0.224	0.284	0.662
	SD	*1.117*	*3.982****		
	Circulatory lane width (m)	-0.182	-2.912***	-0.178	-1.569
	Entry width (m)	0.213	2.937***	0.248	2.419**
	Traffic signal (1 if signal;0 otherwise)	-0.145	-0.492	0.215	0.395
	SD	*0.945*	*5.818****		
	Traffic signal (1 if un-signal;0 otherwise)	-0.017	-0.069	0.364	0.895
	SD	*0.842*	*4.574****		
	Traffic Characteristics				
	ln(AADT)	1.37	6.112***	1.08	3.440***
	Percentage of Average annual daily truck traffic	0.14	4.463***	0.110	1.618
	Dispersion parameter	1.81	5.448***	0.917	5.267***
	Observation numbers	70		70	
	Log-likelihood at constant only	-407.4612			
	Log-likelihood at convergence	-396.8231		-401.1357	
Within circulatory lanes	**Constant**	-10.87	-7.068***	-6.93	-1.108
	Geometric characteristics				
	ICD (m)	0.012	8.564***	0.006	1.198
	Circulatory lane width (m)	-0.266	-5.283***	-0.45	-3.302***
	Two-lane indicator	-1.86	-9.135***	-0.67	-0.847
	SD	*1.66*	*10.331****		
	Traffic signal (1 if un-signal;0 otherwise)	-1.51	-5.644***	-2.05	-2.652***
	Traffic signal (1 if signal;0 otherwise)	-0.082	-0.654	0.338	0.452
	SD	*1.153*	*13.072****		
	Traffic Characteristics				
	ln(AADT)	1.28	9.449***	1.16	1.702*
	Percentage of Average annual daily truck traffic	0.056	3.300***	0.21	2.626***
	Dispersion	18.95	2.118**	0.55	4.318***
	Observation numbers	70		70	
	Log-likelihood with constant only	-234.5069			
	Log-likelihood at convergence	-198.4219		-209.8665	

Table 7-1 Continued

At approaches	**Constant**	-13.36	-11.536***	-9.56	-5.458
	Geometric characteristics				
	Entry Width (m)	0.046	1.466	0.033	0.543
	SD	*0.026*	*4.650****		
	Traffic signal (1 if signal;0 otherwise)	0.41	2.952***	0.25	1.321
	SD	*0.357*	*4.473****		
	Lane number (1 if lane number=2;0 otherwise)	-0.56	-4.103***	-0.36	-2.099**
	SD	*1.28*	*13.299****		
	Grade type (1 if grade separated; 0 otherwise)	-0.78	-5.366***	-0.52	-2.193**
	SD	*0.98*	*14.958****		
	Traffic Characteristics				
	ln(AADT)	1.60	12.674***	1.29	6.465***
	Percentage of average Annual Daily Truck Traffic	0.16	8.387***	0.115	3.175***
	Dispersion parameter	1.33	9.643***	0.462	10.479***
	Observation numbers	284		284	
	Log-likelihood with constant only	-1154.866			
	Log-likelihood at convergence	-1093.753		-1111.236	

* At 90% significance level ** At 95% significance level *** At 99% significance level

Within the circulatory, the results show that the log-likelihood at convergence for the random-parameters model is better when it is compared to the fixed-parameters model; and according to the log-likelihood test ratio, the χ^2 statistic value, Eq. (3-12), of 22.8892 with two degrees of freedom results in greater than 99.99% confidence that the random-parameters model is better. In addition, Figure 7-2 illustrates a better overall fit with the random-parameters model when actual values are related to predicted values.

At approaches, the log-likelihood at convergence for the random-parameters model is better when it is compared to the fixed-parameters model; and according to the log-likelihood test ratio; the χ^2 statistic value, Eq. (3-12), of 34.966 with three degrees of freedom results in greater than 99.99% confidence that the random-parameters model is better. In addition, Figure 7-3 illustrates a better overall fit with the random-parameters model when actual values are related to predicted values.

Table 7-2 HBI Average Marginal Effects Results

Roundabout category	Variable	NB Random parameters model	NB Fixed parameters model
Whole roundabout	Arm number (1 if 3 arm;0 otherwise)	5.24	32.1
	Circulatory lane width (m)	-14.87	-20.11
	Entry width (m)	17.47	28.11
	Traffic signal (1 if signal;0 otherwise)	-11.86	24.30
	Traffic signal (1 if un-signal;0 otherwise)	-1.42	41.11
	ln(AADT)	112.31	122.85
	Percentage of average annual daily truck traffic	11.47	12.50
Within circulatory lanes	ICD (m)	0.03	0.04
	Circulatory lane width (m)	-0.54	-2.94
	Two-lane indicator	-3.75	-4.36
	Traffic signal (1 if un-signal;0 otherwise)	-3.1	-13.3
	Traffic signal (1 if signal;0 otherwise)	-0.17	2.18
	ln(AADT)	2.60	7.51
	Percentage of average annual daily truck traffic	0.113	1.33
At approaches	Entry Width (m)	0.44	0.68
	Traffic signal (1 if signal;0 otherwise)	3.87	5.34
	Lane number (1 if lane number=2;0 otherwise)	-5.30	-7.66
	Grade type (1 if grade separated; 0 otherwise)	-7.44	-10.97
	ln(AADT)	15.15	27.21
	Percentage of average annual daily truck traffic	1.47	2.42

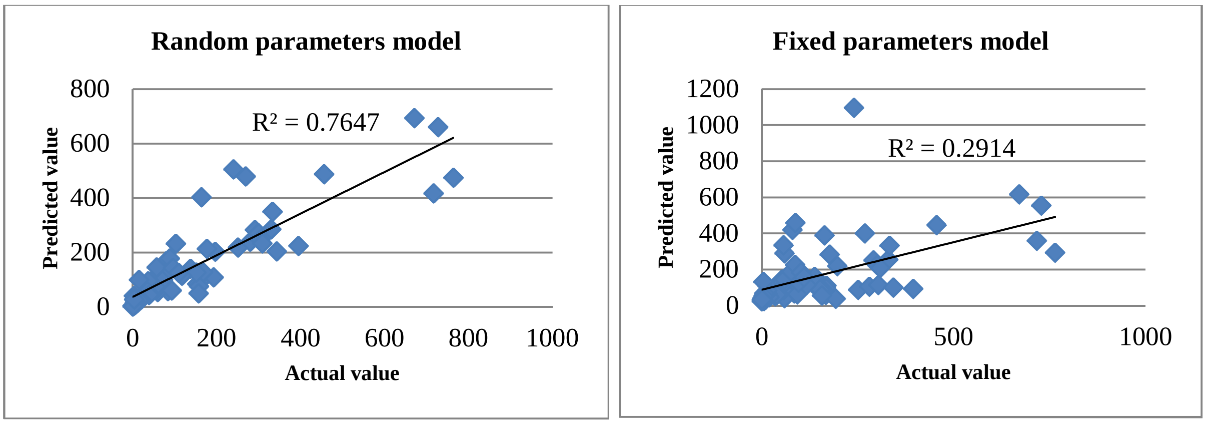


Figure 7-1 Predicted Values and Actual Values of HBIs of Random and Fixed-Parameters NB Models for Whole Roundabouts

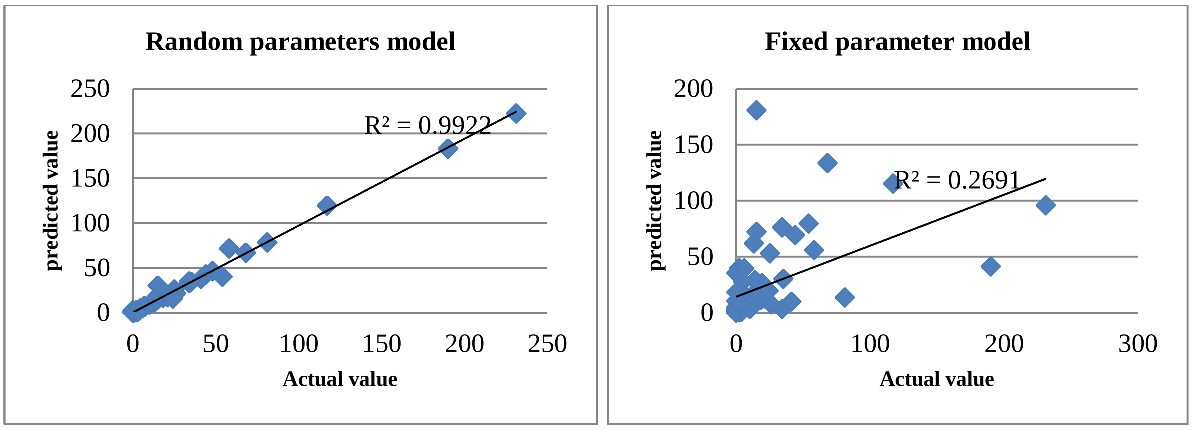


Figure 7-2 Predicted Values and Actual Values of HBIs of Random and Fixed-Parameters NB Models Within Circulatory Lanes

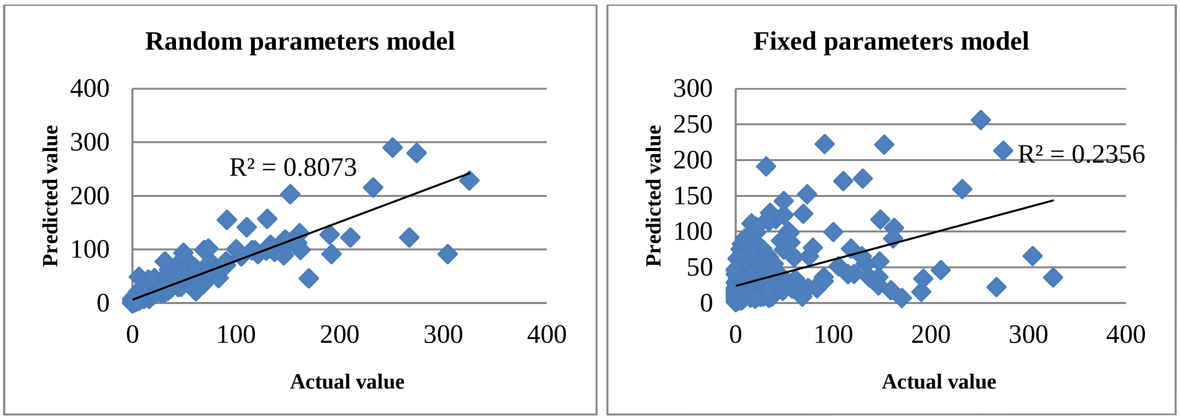


Figure 7-3 Predicted Values and Actual Values of HBIs of Random and Fixed-Parameters NB Models at Approaches

For each roundabout category, all the variables presented in Tables 3-9a to c were tested in order to find their significance. Note that as the type of grade was correlated to ICD, the type of grade for whole roundabouts and within circulatory lanes was removed from the model. However, different models were estimated based on the type of grade; these are presented in the next sections.

For the whole roundabouts, the exposure variables (geometric and traffic variables) that were used to predict total and truck accidents within the whole roundabout are used to predict HBIs. The following variables were found to have a significant effect on HBIs, but their effect was fixed across the selected roundabouts in the random-parameters models:

- Circulatory lane width,
- Entry width,

- AADT, and
- Percentage of average annual daily truck traffic.

The influence of the following variables on HBIs were significantly varied across the selected whole roundabouts:

- Three-arm indicator,
- Signalised roundabouts, and
- Un-signalised roundabouts.

A parameter is considered random when the SD of the parameter distribution is statistically different from zero (if the estimated SD of the variable is not statistically different from zero then the variable is fixed across the observations).

Examining whole roundabouts, the effect of three-arm indicator was varied across the observations having a normal distribution with a mean of 0.064 and a SD of 1.117. Based on this distribution, 52% of the three-arm roundabouts had higher numbers of HBIs (with 47.7% having lower numbers of HBIs). Average marginal effect (see Table 7-2), shows that roads with three arms are associated with higher numbers of HBIs by an average of 5.24 over a two-year period. Note that the three-arm indicator was found to be insignificant in the NB fixed-parameters model. The selected locations include 12 three-arm roundabouts and six (52%) of them have a higher number of HBIs (Bromley Heath, Chester Rd, Lodge Lane, A46/A17, A63/A19, and A1237/A64). Two of them are signalised, and the others are un-signalised. In these locations 1,382 HBIs were recorded (a rate of 230 HBIs/roundabout), while in the other six locations only 24 HBIs were recorded (a rate of 4 HBIs/roundabout). Note that at the Chester Rd, Lodge Lane, and A46/A17 roundabouts, it was found that the truck percentage is high, varying from 9.5 to 10%. Note also that in four and five-arm roundabouts a high number of HBIs were identified, but their effect was found to be insignificant across the whole roundabouts.

Circulatory lane width was found to have a statistically highly significant effect on decreasing the number of HBIs (*t*-statistic was significant at 99% significance level (see Table 7-1)). A 1 m increase in circulatory roadway width decreases the number of HBIs by an average of 14.87 (see Table 7-2). This effect was found to be insignificant in the NB fixed-parameters model. However, the same effect was found for truck accidents, indicating that probably higher circulatory roadway width brings more comfort for truck drivers, leading them to drive more safely, and this matches the findings made by Milton and Mannering (1998) and Miaou (1994), who in an examination of road segments found that in three-lane roads other vehicles usually do not change their lanes in the presence of trucks and hence roads become safer, although these studies concerned total accidents.

Entry width was found to have a significant effect on increasing the numbers of HBIs, by an average of 17.5 over the two-year period per 1m increase (an average of 28.11 in the NB fixed-parameters model). However, at whole roundabouts, entry width resulted in an insignificant effect for both total and truck accidents. The probable reason behind this effect is that higher entry width is associated with higher traffic volume as stated by Kimber (1980), and in addition higher entry width probably makes the driver feel that there is more space to overtake or pass the approach at a higher speed; as Arndt (1998) stated, the speed of vehicles can be reduced by decreasing entry width, and Dingus et al. (2006) noted that event severity (accident, incident, and near-miss accidents) increases with increasing speed.

Signalised roundabouts result in a random parameter, in which 56% of the roundabouts with signals present had lower numbers of HBIs (and the remaining 44% had higher numbers of HBIs). From Table 7-2, the presence of traffic signals decreases the number of HBIs by an average of 11.86. In contrast, signalised roundabouts were found to have an insignificant influence in the NB fixed-parameters model. The selected locations comprise 20 signalised roundabouts as a whole, nine of them have higher numbers of HBIs, 3,660 HBIs were recorded in these locations (a rate of 183 HBIs/roundabout), and they consist of one three-arm, five four-arm, and three five-arm roundabouts, all but one of them are grade-separated. Across the other 11 locations only 540 HBIs were recorded (a rate of 49 HBIs/roundabout).

Un-signalised roundabouts result in a random parameter: 51% of the un-signalised roundabouts had a lower number of HBIs, while 49% had higher numbers of HBIs. Table 7-2 reveals that un-signalised roundabouts are associated with lower numbers of HBIs by an average of 1.42 in the random-parameters model. In the NB fixed-parameters model un-signalised roundabouts were found to have a statistically insignificant effect on HBIs. The selected roundabouts comprise 28 un-signalised roundabouts, half of which (14) have higher numbers of HBIs. 2,538 HBIs were recorded in these locations (a rate of 181.3 of HBIs/ roundabouts), relative to 129 in the locations that had lower numbers of HBIs (a rate of 9.21 HBIs/roundabout). Eight out of 14 of the locations with the un-signalised indicator that had higher numbers of HBIs are at-grade roundabouts, have high entry width, high truck percentages and the majority of them have four arms as shown in Figure 6-9 where the locations within the orange circle had higher HBIs with higher truck traffic percentage. The locations that recorded lower numbers of HBIs have lower percentages of truck traffic and half of them are at-grade roundabouts. According to Table 6-2, all the roundabouts that are un-signalised see the lowest number of HBIs, while higher numbers of HBIs were recorded at signalised and partially signalised roundabouts. This indicates that probably signalisation alone has its own effect on driver behaviour, as HBIs will occur if the driver is not aware of the signals as they approach the roundabouts. This fits the results of Inman et al. (2006), who found that harsh decelerations were recorded by test trucks at intersections when the driver could not catch the green light, resulting in a deceleration of 0.67 g (6.6 m/s^2) covering a distance of 55m over one second. Harbluck et al. (2007) state that 85% of HBIs occurred at signalised intersections. However, more studies are required on driver behaviour when approaching different roundabouts based on different traffic control systems.

AADT and percentages of truck traffic were found to have a high impact on increasing the number of HBIs (*t*-statistic is significant at 99% confidence level). They were both found to have fixed effects across the observations, and Table 7-1 shows that the number of HBIs increases by 1.37% for a 1% increase in AADT, and Table 7-2 shows that a 1% increase in truck traffic increases the number of HBIs by an average of 11.47% over the two-year period.

Within the circulatory lanes, all the variables illustrated in Table 3-9b except type of grade were examined to find their effect on HBI occurrence. The following variables were found to have a significant fixed effect on HBIs:

- ICD,
- Circulatory roadway width,
- Un-signalised circulatory,
- AADT, and
- Percentage of truck traffic.

The influence of the following variables on the occurrence of HBIs was significantly varied across observations, because statistically the SD of the variable was found to be different from zero, which is indicated by the *t*-statistic (see Table 7-1):

- Two-lane circulatory, and
- Signalised circulatory.

ICD was found to have a significant effect on increasing the number of HBIs within the circulatory lanes (the *t*-statistic is significant at 99% significance level (see Table 7-1)). It was found that a10 m increase in the ICD increases HBIs by an average of 0.3. However, the influence of the ICD was found to be insignificant in the fixed-parameters model. Note that according to the reported marginal effect, the influence of ICD on HBIs is not high, and it was found to have similar influence on total and truck accidents within the circulatory lanes.

It was found that reducing circulatory lane width by 1 m resulted in a decrease in the number of HBIs by an average of 0.54, while in the NB fixed-parameters model the average was 2.94 (see Table 7-2). Circulatory roadway width was found to have an insignificant effect on the occurrence of total and truck accidents within the circulatory. Note that according to the marginal effect the influence of circulatory roadway width and ICD are not high over the two-year period.

The effect of the two-lane indicator was varied across the roundabout circulatory lanes having a normal distribution with a mean of –1.86 and a SD of 1.66, indicating that 87% of the circulatory sections with two lanes had lower numbers of HBIs (with 13% having higher numbers of HBIs). Table 7-2 shows that a two-lane circulatory decreases HBIs by an average of 3.75, while this effect was found to be insignificant in the fixed-parameters model. The selected roundabout circulatory sections comprise 40 two-lane locations, 35 of them have fewer HBIs, and the other five have more. Four of the five locations that have higher numbers of HBIs with a two-lane circulatory were found to be grade-separated, and have high percentages of truck traffic. 208 HBIs were recorded in the five locations (a rate of 41.6 per roundabout), while only 41 HBIs were recorded in the other 35 locations (a rate of 1.2 per roundabout), of which 26 are un-signalised, one is signalised and the remaining eight are partially signalised: the majority of these HBIs were recorded in partially signalised circulatory lanes. Note that Figure H-5, Appendix H, indicates that within the circulatory lanes, AADT is lower for two-lane compared to three-lane circulatory sections, and this might be the reason for the lower HBI numbers in a two-lane circulatory, while the percentage of truck traffic in two and three lanes is nearly the same. In addition, Table 6-6 illustrates that within circulatory lanes HBIs highly related to AADT in partially signalised roundabouts and this might be the reason for having higher number of HBIs in these locations.

An un-signalised circulatory leads to fewer HBIs, and Table 7-2 shows that circulatory lanes which are un-signalised had a statistically highly significant fixed impact on decreasing the number of HBIs (*t*-statistic is significant at 99% significance level). Table 7-2 shows that an un-signalised circulatory is associated with lower numbers of HBIs by an average of 3.1 (in contrast the average marginal effect was 13.3 in the fixed-parameters model). Comparing the results with accidents, it was also found that un-signalised circulatory lanes have lower numbers of total and truck accidents. Fewer HBIs are seen in un-signalised circulatory sections because the majority of them are at-grade, and Figure H-6, Appendix H, reveals that they have lower AADT relative to signalised and partially signalised roundabouts.

Signalised circulatory sections were found to vary across the observations: 53% of the signalised circulatory sections have fewer HBIs, while the other 47% have more. Table 7-2 demonstrates that HBIs decrease by an average of 0.17 with the presence of signals within the circulatory lanes. This effect is very small over two-year period. The selected roundabouts have 21 signalised circulatory sections, 11 of which have fewer HBIs, the other ten more: 778 HBIs were recorded in the ten locations relative to 78 HBIs in the remaining 11 (a rate of 77.8 relative to 7.1 per roundabout). There is not much difference between the locations that have high and low numbers of HBIs with traffic signal presence, but 19 of them are grade-separated and have three lanes, which are the causes of higher HBI numbers in signalised circulatory lanes.

As AADT is in logarithmic form in the model, so based on the regression coefficient a 1% increase in AADT, the number of HBIs within the circulatory lanes of the roundabout increases by 1.28% (see Table 7-1). Within the circulatory lanes for the majority of roundabout geometric factors a linear relationship was identified between HBIs and AADT (see Table 6-6). However, AADT was found to have an insignificant effect on circulatory total and truck accidents. In addition, Table 7-2 illustrates that a 1% increase in the percentage of truck traffic increases circulatory HBIs by an average of 0.113% over the two-year period.

At approaches to the roundabouts, all the variables illustrated in Table 3-9c were examined to identify their influence on the occurrence of HBIs. The following variables were found to have significant fixed effects on increasing the number of HBIs across the selected approaches:

- AADT at approaches, and
- Percentage of truck traffic at approaches.

The effects of the following geometric variables on HBIs were found to vary across the approaches:

- Entry width,
- Signalised approaches,
- Two-lane approaches, and
- Type of grade indicator.

Table 7-1 illustrates that effect of the entry width was varied across the approaches with a normal distribution having mean of 0.046 and a SD of 0.026. Based on these distributions, 96% of the distribution is greater than zero (this indicates that for the majority of the roundabout approaches, larger entry width corresponds to a higher number of HBIs). For the fixed-parameters model it was found that entry width had an insignificant effect on the number of HBIs. An increase in entry width of 1 m increases the number of HBIs by an average of 0.44 over two years (see Table 7-2). As discussed earlier, higher entry width is associated with higher traffic volume, and in addition probably in case of low traffic volume in locations with high entry width, the speed of the vehicles increases, which may make the approaches less safe.

Signalised approaches result in a random parameter, in which 87.5% of the approaches with traffic signals have higher numbers of HBIs (and 12.5% of signalised approaches have fewer HBIs). This shows that the effect of approach signalisation varies significantly across the roundabout approaches. Note that these indicators were found to have an insignificant effect on HBIs in the fixed-parameters model (as indicated by the *t*-statistic (see Table 7-1)). The marginal effects shown in Table 7-2 reveal that the presence of signalised approaches is associated with higher numbers of HBIs by an average of 3.87. The selected roundabouts have 142 signalised approaches, 124 of which have more HBIs, while the other 18 recorded fewer, with only six HBIs recorded in these 18 locations (a rate of 0.33 HBI per roundabout) while 5,784 HBIs were recorded in the other 124 locations (a rate of 46.64 HBIs per roundabout). The selected approaches which recorded lower HBI numbers have lower traffic volumes, and 15 of them are located on A-class roads.

The two-lane indicator results in a random parameter, in which 67% of two-lane approaches have a lower number of HBIs (with 33% having more). The average marginal effect reveals that two-lane approaches are associated with lower HBIs by an average of 5.30 over the two-year period (in the fixed-parameters model the average is 7.66). Of the selected roundabouts, 172 have two-lane approaches, 115 (86 A- and B-class roads and 29 M-class roads) of which have fewer HBIs and 57 of which have more. Over the 57 approaches, 3,503 HBIs were recorded (a rate of 61.45 HBI per roundabout), while for the other 115 locations, 262 HBIs were recorded (a rate of 2.27 HBI per roundabout). The locations that have more HBIs with two lanes have higher truck percentages, out of 57, 33 of them are located on A-class roads, and 24 on M roads. Note that Lee et al. (2007) have found that at intersections there is no relationship between HBIs and near-miss accidents with the number of traffic lanes, probably because their study includes all types of manoeuvres, not only HBIs, and was done at other types of intersections; in addition they used linear regression.

The grade type indicator results in a random parameter, in which 78% of the approaches that are grade-separated have lower numbers of HBIs (with 22% having more HBIs). The average marginal effect reveals that approaches that are located at grade-separated roundabouts have lower HBIs by an average of 7.44 over the two-year period (for the fixed-parameters model the average is 10.97). The selected grade-separated roundabouts have a total of 211 approaches, 165 (78%) of them have fewer HBIs, while the other 46 (22%) recorded more HBIs. 1,518 HBIs were recorded at the 165 approaches (a rate of 9.2 HBIs per roundabout), of these 739 HBIs were recorded on 97 A- and B-class roads (a rate of 7.6 HBIs per roundabout), and 779 were recorded on 68 M-class roads (a rate of 11.45 HBIs per roundabout). For the 46 approaches that saw higher HBI numbers (5,123 HBIs were recorded corresponds to a rate of 111.4), 26 are on M-class roads, recording 2,917 HBIs (a rate of 112.2 per roundabout), and 2,206 HBIs were recorded at the other 20 A-class approaches (a rate of 110.3 per roundabout), located on A-class roads, virtually identical results. It was found that the majority of the approaches that recorded high numbers of HBIs are signalised (26 out of 46) and have high percentages of truck traffic.

The traffic related variables – AADT and percentage of truck traffic – were both found to have high fixed effects increasing the number of HBIs (as indicated by the *t*-statistic in Table 7-1). As AADT increases by 1% the number of HBIs increases by 1.60%. A 1% increase in the percentage of truck traffic results in an average 1.47% increase in the number of HBIs (for the fixed-parameters model a 1% increase in the percentage of truck traffic the average results in an average 2.42% increase in the number of HBIs which is quite different from the random-parameters model). This indicates that if unobserved heterogeneity is not considered different marginal effects will acquire and and may leads to wrong conclusions.

7.3 Harsh Braking Incident Model for Grade-Separated Roundabouts

Whole grade-separated and at-grade roundabouts were analysed separately, in order to examine the main factors influencing harsh braking occurrence for each type of grade. As identified in Section 6.4.1 and Figure H-4 (Appendix H), grade-separated roundabouts showed different trends with the same level of traffic to at-grade roundabouts, and moreover because of the collinearity results (see Table 5-1a) ICD was highly correlated to type of grade, for this reason models were identified separately for at-grade and grade-separated roundabouts. In addition, this allows comparison of the results for each type of grade to the results acquired for total and truck accidents, which is presented in next Chapter. This section illustrates the random-parameters NB models that are identified for grade-separated locations and are compared to the fixed-parameters NB models.

Table 7-3 presents the random and fixed-parameters NB estimated model results. Table 7-4 illustrates the average marginal effects estimated by the models. The results show that for grade-separated roundabouts, the log-likelihood at convergence for the random-parameters model is better than for the fixed-parameters model, and according to the log-likelihood test ratio, the χ^2 statistic value, Eq. (3-12), of 6.0786 with two degrees of freedom results in a 95% confidence that the random-parameters model is better. In addition, Figure 7-4 illustrates that a better overall fit for the random-parameters model relative to the fixed-parameters model was acquired when actual values are related to predicted values.

For grade-separated locations, all the variables illustrated in Table 3-9a were examined except the three-arm indicator, as all the studied three-arm roundabouts are at-grade, and the following variables were found to have significant fixed effects on HBIs:

- Four-arm indicator,
- Five-arm indicator,
- ICD,
- Entry width,
- AADT, and
- Percentage of truck traffic.

The influence of the following variables on HBIs was varied across the observations (as the SD of the distributed parameter is statistically different from zero as indicated by the *t*-statistic (see Table 7-3).

- Signalised grade-separated roundabouts, and
- Un-signalised grade-separated roundabouts.

Note that in the fixed-parameters models all the variables were found to have insignificant effects on HBIs, except entry width which had a fixed positive effect on HBI numbers.

Table 7-3 HBI Model Estimation Results for Grade-Separated Roundabouts

Variables	NB Random-parameters model		NB Fixed-parameters model	
	Coefficient	*t*-stat	coefficient	*t*-stat
Constant	-12.24	-3.518***	-6.28	-1.320
Geometric characteristics				
Arm number (1 if 4 arm;0 otherwise)	0.78	2.232**	0.88	1.522
Arm number (1 if 5arm;0 otherwise)	0.97	2.053**	1.07	1.498
ICD (m)	0.007	1.832*	0.007	1.117
Entry width	0.16	1.780*	0.21	1.669*
Traffic signal (1 if signal;0 otherwise)	-0.082	-0.265	0.24	0.566
SD	*0.83*	*4.168****		
Traffic signal (1 if un-signal;0 otherwise)	0.0002	0.001	0.084	0.129
SD	*0.90*	*4.070****		
Traffic Characteristics				
ln(AADT)	1.15	3.795***	0.58	1.558
Percentage of average annual daily truck traffic	0.08	2.211**	0.05	0.683
Dispersion parameter	1.83	4.711***		
Observation numbers	51		51	
Log-likelihood with constant only	-307.3265			
Log-likelihood at convergence	-290.1212		-293.1650	

* At 90% significance level ** At 95% significance level *** At 99% significance level

Table 7-4 HBI Average Marginal Effects Results for Grade-Separated Roundabouts

Variable	NB Random parameters model	NB Fixed parameters model
Arm number (1 if 4 arm;0 otherwise)	72.5	101.7
Arm number (1 if 5 arm;0 otherwise)	89.3	116.93
ICD (m)	0.68	0.79
Entry width	14.7	23.82
Traffic signal (1 if signal;0 otherwise)	-7.53	27.8
Traffic signal (1 if un-signal;0 otherwise)	0.021	9.65
ln(AADT)	106.42	67.12
Percentage of average annual daily truck traffic	7.37	5.88

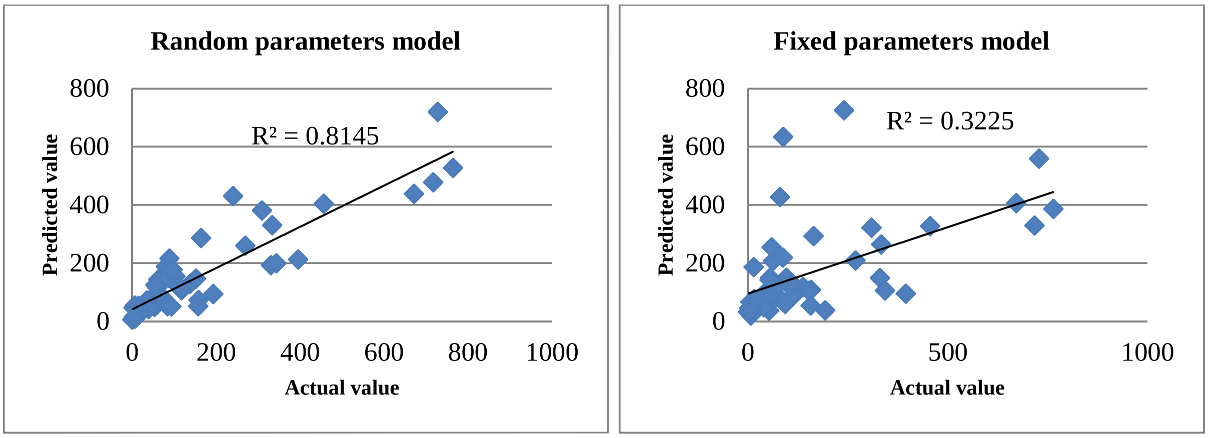


Figure 7-4 Predicted Values and Actual Values of HBIs of Random and Fixed-Parameters NB Models for Grade-Separated Roundabouts

Four-arm and five-arm roundabouts were found to have a significant fixed effect on increasing HBIs, the marginal effect in Table 7-4 illustrates that the number of HBIs increases by an average of 72.5 and 89.3 with the presence of four and five arms, respectively. Six-arm roundabouts have lower numbers of HBIs. However, as the number of arms increases, traffic volume and conflict point's increase and this can affect the roundabout safety. However, the number of six-arm roundabouts investigated in this study was low, so further investigation is required with higher number of observations regarding this effect.

ICD and entry width were both found to have statistically significant effects on HBIs: a 10 m increase in ICD and a 1 m entry width increase HBIs by an average of 6.8 and 14.7, respectively, over the two-year period. For the whole roundabout, ICD was found to have an insignificant effect at 70 locations, indicating that HBI numbers in at-grade locations are not diameter dependent.

Table 7-3 illustrates that the effect of the signalised indicator was varied across the grade-separated roundabouts in which 54% of the distribution has fewer HBIs with the presence of traffic signals. Traffic signal presence is associated with an average of 7.53 fewer HBIs over two years (see Table 7-4). The selected grade-separated roundabouts comprise 18 signalised roundabouts, ten of which have higher numbers of HBIs (3,544 corresponds to a rate of 354.4 per roundabout), with the other eight having fewer HBIs (569 corresponds to a rate of 71.1 per roundabout). The ten locations that have higher HBIs with signalisation are Gilda Brook, A1/A14, A14/A141, J13, J16, and J18 on the M4, J10, and J40 on the M6, and J28 and J33 on the M1. Five of these have four arms while the other five have five arms, and seven of them have three lanes within the circulatory. In addition, these locations have high percentages of truck traffic.

Un-signalised grade-separated roundabouts result in random parameters, in which 51% of the approaches without signals have more HBIs (49% have fewer). Marginal effects show that HBIs increase by an average of 0.021 when the roundabouts are un-signalised (see Table 7-4): this effect is very low over the two-year period. In addition, of the selected grade-separated roundabouts, 13 are un-signalised, seven of which have higher numbers of HBIs (733, corresponds to a rate of 56.4 per roundabout), with the remaining six having fewer HBIs (51, corresponds to a rate of 8.5 per roundabout). All the grade-separated roundabouts that are un-signalised have four arms, and the locations that have more HBIs were found to have higher percentages of truck traffic and higher entry width relative to the locations that had fewer HBIs. Signalised and un-signalised effects on HBI occurrences have varied across grade-separated roundabouts mainly because of the percentage of truck traffic, entry width, and higher ICDs. In addition, variations probably due to the driver behaviour that is unknown during this analysis with respect to traffic control which is considered as an unobserved heterogeneity.

Traffic related variables – AADT and the percentage of truck traffic – were both found to have high impacts on increasing the number of HBIs (as indicated by the *t*-statistic in Table 7-1). As AADT increases by 1% the number of HBIs increases by 1.15%. A 1% increase in the percentage of truck traffic increases the number of HBIs by an average of 7.37%. In the fixed-parameters model, however, it was found that both AADT and percentage of truck traffic have insignificant effects on HBIs; it is a well-known fact that traffic characteristics have a high influence on the safety performance of road networks, including at roundabouts and intersections (See Table 2-1 and Table 2-8, for the influence of traffic variables AADT and truck percentage on accidents). This indicates that the random-parameters model better predicts the influence of the traffic variables on HBIs and accidents.

7.4 Harsh Braking Incident Model for At-Grade Roundabouts

As discussed previously, whole grade-separated and at-grade roundabouts were analysed separately, because of the reasons discussed in previous section, and in order to examine the main factors influencing the occurrence of HBIs for at-grade locations. This section illustrates the random-parameters NB models that are identified for at-grade locations and compares them to the fixed-parameters NB models.

Table 7-5 presents the random and fixed-parameters NB model estimation results, and Table 7-6 illustrates the average marginal effects estimated by the models. The results show that for at-grade roundabouts, the log-likelihood at convergence for the random-parameters model was better when it is compared to the fixed-parameters model. And according to the log-likelihood test ratio the χ^2 statistic value Eq. (3-12) of 4.5872 with one degree of freedom results in 97% confidence that the random-parameters model is statistically more significant. In addition, Figure 7-5 illustrates that a better overall fit was identified for the random-parameters model relative to the fixed-parameters model when actual values are related to predicted values. However, for truck accidents at at-grade roundabouts only a fixed parameter model was identified because signalisation and AADT were found to have a fixed effect on truck accidents

Table 7-5 HBI Model Estimation Results for At-Grade Roundabouts

Variables	NB Random-parameters model		NB Fixed-parameters model	
	coefficient	*t*-stat	coefficient	*t*-stat
Constant	-28.23	-8.782***	-33.41	-4.579***
Geometric characteristics				
Lane number (1 if 2 lanes;0 if three)	0.74	2.652***	1.50	1.328
SD	*1.11*	*7.922****		
Traffic signal (1 if signal;0 if otherwise)	1.78	3.619***	1.56	0.962
Traffic Characteristics				
ln(AADT)	0.33	6.196***	3.26	5.295***
Percentage of average annual daily truck traffic	2.82	9.862***	0.39	2.776***
Dispersion parameter	6.55	2.204**	1.09	2.112**
Observation number	19		19	
Log-likelihood with constant only	109.1352			
Log-likelihood at convergence	-98.33		-100.6236	

* At 90% significance level ** At 95% significance level *** At 99% significance level

Table 7-6 HBI Average Marginal Effects Results for At-Grade Roundabouts

Variable	NB Random parameters model	NB Fixed parameters model
lane number (1 if lane is two;0 if three)	36	109
Traffic signal (1 if signal;0 otherwise)	86	113
ln(AADT)	136	236
Percentage of average annual daily truck traffic	15.7	28

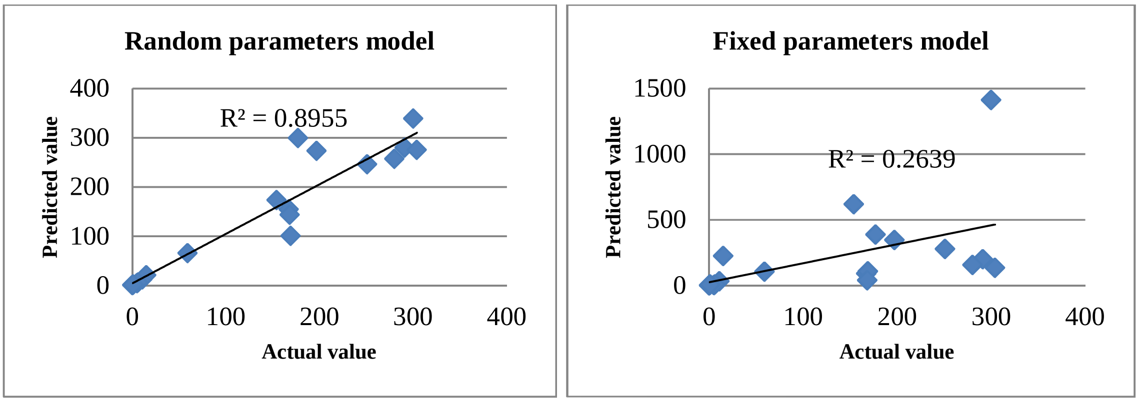


Figure 7-5 Predicted Values and Actual Values of HBIs of Random and Fixed-Parameters NB Models for At-Grade Roundabouts

All the variables illustrated in Table 3-9a except type of grade for at-grade locations were examined, in addition because the majority of at-grade roundabouts are three-arms only the effect of the three-arm indicator were examined (i.e 1 if three-arm; 0 otherwise). The following variables were found to have significant fixed effects on increasing HBIs:

- Signalised at-grade roundabouts,
- AADT, and
- Percentage of truck traffic.

The influence of the two-lane indicator on HBIs varies across at-grade roundabouts (as the SD of the variable distribution is statistically different from zero, as indicated by the *t*-statistic (see Table 7-5)). 75% of at-grade roundabouts have higher numbers of HBIs with the two-lane indicator, and the other 25% have lower numbers of HBIs with the two-lane indicator. The average marginal effect illustrates that HBIs increase by an average of 36 when at-grade roundabout has two lanes (see Table 7-6). Note that this effect was found to be insignificant in the fixed-parameters model. Out of 19 at-grade roundabouts 15 of them have two-lanes and of the 15 selected at-grade roundabouts, 11 of them have more HBIs (1,715, corresponds to a rate of 156 per roundabout), and four of them have fewer (7, corresponds to a rate of 1.75 per roundabout). The four locations which recorded fewer HBIs all have three arms, of the other 11 locations, three of them have four arms, and two of them have five arms. Four of the at-grade locations have three lanes and higher numbers of HBIs were recorded in these three lanes, indicating that as the number of lanes increases, so do HBIs. Note that for grade-separated locations, the two-lane indicator was found to have a statistically insignificant effect on HBIs.

All at-grade roundabouts that are signalised were found to have higher numbers of HBIs. The average marginal effect indicates that HBIs increase by an average of 86 over the two-year period. This effect was found to be insignificant, however, in the fixed-parameters model. This indicates that signalisation for small roundabouts increase the chance of HBIs. However, the majority (15) of the selected at-grade roundabouts are un-signalised, two are signalised and the other two are partially signalised. This means that there are only two at-grade signalised roundabouts, so further investigation is required in order to explore this effect with more observations.

The traffic related variables, AADT and percentage of truck traffic – were both found to have a high impact on increasing the number of HBIs (as indicated by the *t*-statistic in Table 7-5). As AADT increases by 1% the number of HBIs increases by 0.33%. A 1% increase in the percentage of truck traffic results in an average 15.7% increase in the number of HBIs.

7.5 Discussion, Summary and Conclusions

The random-parameters model was found to have a better fit, and a better prediction for HBIs relative to the fixed-parameters model for whole roundabouts, within circulatory lanes, and at approaches, and for grade-separated and at-grade locations. It was found that the random-parameters model is significant at 99% and 95% confidence intervals, and more variables were found that randomly affect the incidents of harsh braking which were not significant in the fixed-parameters model. The mean predicted values compared to the actual values of HBIs provide a better overall fit with the random-parameters model than with the fixed-parameters model.

Table 7-7 provides a summary of the significant variables in the random-parameters model and their influence (fixed or random) with marginal effects on HBIs.

It should be noted that, regarding HBI data that are used in this study, one might think that these HBIs occurred just because the traffic light turned red as mentioned in euroFOT (Faber et al., 2011) and in 100-car NDS (Dingus et al., 2006) and in such case it is not considered as a safety risk indicator. However, in the thesis signalised, un-signalised, and partially signalised roundabouts were studied. In addition, the HBIs included in this study occurred not only at the entry of the roundabouts but within 350m from the roundabout centre. This shows that not only signalisation influenced the occurrence of these HBIs. Based on the results illustrated in this chapter for whole roundabouts, and within circulatory lanes, signalised and un-signalised indicators were studied and compared to partially signalised roundabouts. Their effect for whole roundabouts varied across the observations (see Table 7-7). Within circulatory lanes the influence of un-signalised circulatory was fixed and that of signalised circulatory lanes varied across the observations. Moreover, at approaches signalised approaches were compared to un-signalised approaches, and their effect varied across the approaches. The point is that because their effect varied across the observations and this indicates unobserved heterogeneity, this means it is not only the availability or absence of signals that influenced the occurrence of these HBIs; probably as indicated in this chapter, there are other factors which lead drivers to brake at signalised or un-signalised roundabouts, for instance, higher percentage of truck traffic, higher AADT, higher number of lanes. Therefore the consideration of harsh braking HBIs is important at roundabouts.

It can be concluded that the occurrence of HBIs for all types of roundabout is highly correlated to the percentage of truck traffic: the majority of locations that recorded high HBI numbers had high percentages of truck traffic. High rates of HBIs were recorded in the majority of three-arm roundabouts, and it was found that this corresponded to high truck traffic percentages. In addition, HBIs are highly correlated with the geometric variables examined in this thesis (entry width, ICD, circulatory roadway width, and number of lanes). However, according to the marginal effects, it can be concluded that the influence of entry width on approach HBIs and the effect of ICD and circulatory roadway width on HBIs within the circulatory lanes are small over the two-year period. Two-lane and un-signalised circulatory lanes have a larger effect.

The influence of signalised whole roundabouts on HBIs varied across observations; that some signalised roundabouts recorded higher numbers of HBIs may be because the driver in some cases could not catch the green light and stopped suddenly at a high rate of deceleration, as stated by Inman et al. (2006), who found that harsh deceleration was recorded by test trucks at intersections when the driver could not catch the green light, and Harbluk et al. (2007), who found that 85% of harsh braking occurs at signalised intersections. The models illustrated in this chapter indicate that some signalised and some un-signalised roundabouts recorded very high numbers of HBIs compared with others. The majority of un-signalised roundabouts are at-grade (15 out of 19) and half of them which recorded high numbers of HBIs have high percentages of truck traffic and three arms. Based on these results, it is concluded that un-signalised roundabouts that are at-grade and have three arms and a high percentage of truck traffic (>10%) leading to high numbers of HBIs, which is an indicator for low levels of safety in these roundabouts. In addition from the accident trends it was found that three-arm roundabouts recorded higher fatalities compared to four and five in accidents including trucks.

Table 7-7 Significant Variables Influencing HBIs in the Random-Parameters Models

Roundabout category	Significant variable	Fixed or random effect	Marginal value	Notes
Whole roundabout	Three-arm indicator	Random	5.24	52% of the three-arm roundabouts have more HBIs
	Circulatory roadway width (m)	Fixed	-14.87	HBIs decrease with increasing circulatory roadway width over all roundabouts
	Entry width (m)	Fixed	17.47	HBIs increase with increasing entry width over all roundabouts
	Signalised roundabout	Random	-11.86	52% of the roundabouts with traffic signals have lower HBI numbers
	Un-signalised roundabout	Random	-1.42	51% of the roundabouts that are un-signalised have lower HBI numbers
	AADT	Fixed	1.37%*	As AADT increases, HBI numbers increase
	Truck %	Fixed	11.47%	As the percentage of truck traffic increases, HBI numbers increase
Within circulatory	ICD (m)	Fixed	0.03	As ICD increases, total HBIs increase
	Circulatory roadway width (m)	Fixed	-0.54	Circulatory HBIs decrease with increasing circulatory roadway width
	Two-lane circulatory	Random	-3.75	87% of two-lane circulatory systems have lower HBI numbers
	Un-signalised circulatory	Fixed	-3.1	All circulatory systems that are un-signalised have lower HBI numbers
	Signalised circulatory	Random	-0.17	53% of the signalised circulatory systems have lower HBI numbers
	AADT	Fixed	1.28%*	As AADT increases, HBIs increase within the circulatory lanes
	Truck %	Fixed	0.113%	As truck percentage increases, HBIs increase within the circulatory lanes
At approaches	Entry width (m)	Random	0.44	96% of the approaches have higher HBI numbers when entry width increases
	Signalised approaches	Random	3.87	87.5% of signalised approaches have higher HBI numbers
	Two-lane approaches	Random	-5.30	67% of two-lane approaches have lower incident numbers
	Approaches located on grade-separated roundabouts	Random	-7.44	78% of grade-separated approaches have lower HBI numbers
	AADT	Fixed	1.15%*	As approach AADT increases, HBIs increase
	Truck %	Fixed	1.47%	As approach truck traffic percentage increases, HBIs increase

*Regression coefficient

An un-signalised circulatory was associated with lower levels of HBIs because the majority of the un-signalised circulatory sections are at-grade, and have lower AADT. The signalised approaches that recorded fewer HBIs were found to have lower AADT, and were located on

A-class roads, while signalised approaches with more HBIs had higher truck percentages and were located on M-class roads. The un-signalised grade-separated roundabouts that had higher HBI numbers had higher truck percentages and higher entry widths, resulting in more HBIs, although according to marginal effects this effect is small over the two-year period.

Two-lane approaches were associated with lower HBIs because the majority of them are located on A-class roads. While Lee et al. (2007) found that the number of traffic lanes at intersections is not related to incidents and near-miss accidents, they studied all the manoeuvres included in near-miss accidents, not only HBIs.

Regarding the grade-separated and at-grade locations, Table 7-8 illustrates the influence of each variable in the random-parameters model.

Table 7-8 Significant Variables Influencing HBIs at Grade-Separated and at At-Grade Roundabouts Using the Random-Parameters Model

Roundabout category	Significant variable	Fixed or random effect	Marginal value	Notes
Grade-separated	Four-arm indicator	Fixed	72.5	HBIs increase at four-arm roundabouts
	Five-arm indicator	Fixed	89.3	HBIs increase at five-arm roundabouts
	ICD	Fixed	0.68	HBIs decrease with increasing ICD across all roundabouts
	Entry width	Fixed	14.70	HBIs increase with increasing entry width across all roundabouts
	Signalised roundabout	Random	-7.53	54% of the roundabouts with traffic signals have lower HBI numbers
	Un-signalised roundabout	Random	0.021	51% of the roundabouts that are un-signalised have more HBIs
	AADT	Fixed	1.15%*	As AADT increases, HBI numbers increase
	Truck %	Fixed	7.37%	As the percentage of truck traffic increases, HBI numbers increase
At-grade	Two-lane indicator	Random	36	75% of two-lane at-grade roundabouts have higher HBInumbers
	Signalised roundabouts	Fixed	86	All at-grade roundabouts that are signalised had more HBIs
	AADT	Fixed	0.33%*	As AADT increases, HBIs increase
	Truck %	Fixed	15.7%	As truck percentage increases, HBIs increase

*Regression coefficient

When grade-separated roundabouts were analysed separately from at-grade roundabouts, it was found that ICD and four and five-arm roundabouts are associated with higher HBIs at grade-separated roundabouts, while this effect was found to be statistically insignificant across all 70 roundabouts; note that for the 70 roundabouts, three-arm roundabouts were found to have a random influence, while because all grade-separated roundabouts are four, five, and six-arms, this influence is excluded from the model. However, four and five-arm roundabouts are associated with higher HBIs relative to six-arm roundabouts, and as the number of six-arm roundabouts studied in this thesis is low, more investigation is required on the influence of six-arm roundabouts on harsh braking occurrences.

The main difference between grade-separated and an at-grade roundabout is that geometric measures such as ICD and entry width are not associated with the occurrence of HBIs at at-grade roundabouts. Signalisation and the two-lane indicator were found to be the only geometric variables influencing HBIs at at-grade roundabouts. The two-lane at-grade roundabouts that recorded high numbers of HBIs did so because of high percentages of truck traffic, and high numbers of arms, while the two-lane at-grade roundabouts that were associated with lower HBI numbers all have three arms and lower percentages of truck traffic. And probably bigger roundabouts with two lanes have different traffic situations and driver behaviour from smaller roundabouts with two lanes which leads this variable to vary across observations.

Note that as indicated in Section 2.2, previous studies have related HBIs to driver behaviour or other factors: small headway between the lead and following vehicles by Dingus et al. (2006) and Jamson et al. (2008); lane changing by Fitch et al. (2009) and Jamson et al. (2008); driver misjudgement by Simons-Moton et al. (2009); inappropriate speed and inappropriate braking by Klauer et al. (2009); inattentive driving by Dingus et al. (2006), and Fitch et al. (2009); and using mobile phones at roundabouts by Haque et al. (2016). All of these were found to differ from the factors that this thesis is studying. Firstly, in this study (thesis) traffic and geometric variables were related to HBIs; random parameters NB models were used to examine this relationship; the selected locations were roundabouts not road section or other type of intersections; in addition, the thesis study was based on HBIs of 8000 trucks not small numbers or individual trucks.

It is necessary to compare the results identified in this chapter to the results of total and truck accidents, and the next chapter illustrates this comparison.

Chapter 8 Comparison of Factors Influencing Total accidents, Truck Accidents and Harsh Braking Incidents Models

8.1 Overview

This chapter illustrates the general factors influencing total and truck accidents and HBIs (based on the models identified in Chapter Five and Chapter Seven) in order to explore the possibility of identifying the common factors affecting these three types of accidents/HBIs. In addition, the purpose is to identify locations of high accident risk in the future based on HBIs, which is an objective of this study. The final section discusses, summarises, and draws conclusions for the chapter.

8.2 Summary and Comparison of Factors Influencing Total Accidents and Truck Accidents with Harsh Braking Incident Model Results

8.2.1 Whole Roundabouts

After the models had been identified and illustrated in Chapter Five and Chapter Seven, a number of geometric and traffic-related variables were found to be related to the number of accidents and HBIs. This section compares the HBI model to the total and truck accident model for the whole roundabouts data. Table 8-1 illustrates the effect of each traffic and geometric variable on total accidents, truck accidents, and HBIs for the whole roundabouts using random-parameters models. The limitation of this study is that all accidents (of all severities) as recorded by STATS19 are included in this study, while only the HBI records from Microlise Ltd were included, which does not represent all trucks.

For whole roundabouts, as expected, AADT has a fixed positive[36] effect in a random-parameters model on total accidents, truck accidents, and HBIs (see Table 8-1), which is consistent with all previous studies (Maycock and Hall, 1984; Daniels et al., 2010; Persuade et al., 2001; Šenk and Ambros, 2011; Rodegerdts et al., 2007; Shadpour, 2012; Guitchet, 1997; Montella, 2007; Harper and Dunn, 2005; Turner et al., 2006; AASHTO, 2014). In addition, the percentage of truck traffic was found to have a fixed positive effect on truck accidents and HBIs, and was varied across observations for total accidents, although the majority (86%) of roundabouts have more accidents with a higher truck percentage. The random effect was because of the at-grade locations where an increase in percentage of truck

[36] Fixed positive= the relationship between input and output is always positive at all sites and the estimated regression coefficient is fixed for all sites, as compared with a random relationship where an increase in the input variable may result in both positive and negative change in the input and the estimated regression coefficient is varied for all sites.

traffic does not correlate with an increase in total accidents; all grade-separated roundabouts have higher total accident numbers with a higher percentage of truck traffic.

Table 8-1 Effect of an Increase in Geometric and Traffic Variables on Total Accidents, Truck Accidents, and HBIs using Random Parameters Models for Whole Roundabouts

Variable	Total accident numbers	Truck accident numbers	HBI numbers
ln(AADT)	↑↑	↑↑	↑↑
Percentage of average annual daily truck traffic	86% ↑↑	↑↑	↑↑
Un-signalised roundabouts compared to partially signalised roundabouts	↓↓	↓↓	51% ↓↓
Signalised roundabouts compared to partially signalised roundabouts	-	76% ↓↓	48% ↓↓
Two-lane roundabouts compared to three-lane roundabouts	-	66% ↓	-
ICD	↑	↑	-
Three-arm roundabouts compared to six-arm roundabouts	-	↓↓	48% ↓↓
Circulatory roadway width	-	↓↓	↓↓
Entry width	-	-	↑

Where:

Strong positive | ↑↑ | ↑ | - (no effect) | ↓ | ↓↓ | Strong negative

and % for random parameters (large percentage means that the majority of locations have higher or lower events, while lower percentage means very nearly completely random).

Comparable roundabouts that are un-signalised were associated with lower total and truck accident numbers, but only half of these un-signalised roundabouts were associated with lower HBI numbers. This is probably a study limitation as the Microlise HBIs included in this study did not include braking data from all trucks passing the selected roundabouts. Had they done so, results may have been more similar to those seen for accidents. Note that it is true that un-signalised roundabouts are associated with lower numbers and rates of accidents, but more of those accidents were fatal.

The majority of comparable roundabouts that are signalised were associated with lower truck accidents, and half of the selected locations recorded fewer HBIs. It should be noted that half of the selected roundabouts that are associated with fewer HBIs with signalisation still recorded high HBI numbers and rates relative to un-signalised locations, i.e. signalised roundabouts are generally associated with higher accident and HBI numbers and rates. Therefore, in general, it can be seen that the appropriate roundabouts have been fully signalised and the appropriate ones left un-signalised, to minimise accidents but that this optimisation is not necessary beneficial as regards harsh braking.

Total accidents at three-arm roundabouts were not found to be significantly lower than other roundabouts (i.e. their effect was found to be statistically, insignificant), which contradicts previous studies (Kim et al., 2013; Brude and Larsson, 2000). However, this was found to be the case for truck accidents. The three-arm roundabout was a random parameter in the HBI models (48% showing lower HBIs). This may indicate the influence of unobserved heterogeneity. It should be noted that three-arm roundabouts are associated with lower truck accident rates but with more fatal outcomes is in those accidents.

The majority of two-lane roundabouts were associated with lower truck accident numbers (compared to three-lane roundabouts), while this effect was found to be insignificant on total accident and HBI numbers. However, the marginal effect tells us that this effect is low (-1.88) over the 11-year period and as such the effect of lane number is relatively unimportant as regards truck accidents, total accidents, and HBIs.

Higher ICD is associated with higher total and truck accident numbers, but was found to have an insignificant influence on HBIs. The marginal effect for truck accident numbers (0.41) is low over the 11-year period, so this effect can also be considered relatively unimportant.

Higher circulatory roadway width is associated with lower truck accident and HBI numbers. Circulatory roadway width was found to have an insignificant effect on total accidents (see Table 8-1), while, Kim et al. (2013) found that circulatory roadway width is associated with a lower number of total accidents. Rodegerdts et al. (2007), considering total accident rates (accident/year), stated that higher circulatory roadway width leads vehicles to increase speed and overtake, while lower circulatory width restricts the capacity and the manoeuvrability of vehicles. This possibly illustrates why higher circulatory roadway widths see lower numbers of truck accidents and truck HBIs recorded, because it provides better manoeuvrability for trucks which, because of their size, require more space to negotiate roundabouts.

Entry width is associated with higher HBI numbers but was found to have an insignificant effect on total and truck accidents, while previous studies have found that higher entry width is associated with higher total accident rates (Arndt, 1998; Maycock and Hall, 1984; and Rodegerdts et al., 2007). This may be a case were the more numerous HBIs are revealing a relationship that is not apparent from the smaller number of accidents.

From Chapter Four, and based on previous studies (DfT, 2014; Trucks V, 2013; US Department of Transportation, 2014; Carstensen et al., 2001; Grygier et al., 2007; and Kennedy, 2007), it can be concluded that when truck accidents occur they are generally more severe than other types of accidents and this emphasises the potential importance of analysing truck HBIs in safety analysis. The majority of factors associated with more/fewer truck accident numbers at whole roundabouts are similar to those associated with more/fewer HBI numbers (compare final two columns of Table 8-1), which indicates that truck HBIs could be considered as a variable to indicate assessing safety at locations of potential high accident risk.

8.2.2 Within Circulatory Lanes

Table 8-2 illustrates the effect of each traffic and geometric variable on total accidents, truck accidents, and HBIs within circulatory lanes. A similar analysis is performed as in Section 8.2.1, but is now restricted to circulatory lanes.

ln (AADT) was found to have a statistically insignificant effect on total and truck accidents within circulatory lanes, while this effect was found to be significant for HBIs (see Table 8-2). Previous studies (Maycock and Hall, 1984; Rodegerdts et al., 2007; Harper and Dunn, 2005; Turner et al., 2006) for entering/circulating accidents and (Rodegerdts et al., 2007) for exiting/circulating accidents, have found that as AADT increases total number of accidents increases. The probable reason is that in this study (thesis) circulatory lane includes all accidents occurring within circulatory sections, while previous studies identified this effect on either entering/circulating or for exiting/circulating. In addition previous studies did not estimate the influence of truck traffic or percentage of truck traffic on total accidents within the circulatory lanes, while in this study this effect was considered in the modelling process and was found statistically to have significant effect on total and truck accidents. So this indicates that truck traffic within circulatory lanes is probably more important to consider rather than AADT, because circulatory area is more challenging to truck drivers to manoeuvre and cross it safely.

Table 8-2 Effect of Geometric and Traffic Variables on Total Accidents, Truck Accidents, and HBIs Within Circulatory Lanes

Variable	Total accident numbers	Truck accident numbers	HBI numbers
ln(AADT)	-	-	↑
Percentage of average annual daily truck traffic	↑↑	↑↑	↑↑
Un-signalised roundabouts compared to partially signalised roundabouts	94% ↓↓	93% ↓↓	↓↓
signalised roundabouts compared to partially signalised roundabouts	-	-	53% ↓
Two-lane roundabouts compared to three-lane roundabouts	-	-	87% ↓
ICD	↑	↑	↑
Circulatory roadway width	-	↓↓	↓↓

A higher number of HBIs (1,327) but lower percentage (13%) were recorded within the circulatory lanes, compared to truck accidents (303, 32%); however, (1234, 36%) total accidents recorded within circulatory lanes and still AADT was found to have an insignificant influence. However, according to Table 7-1 a 1% increase in AADT increases HBIs by 1.6%, as an example, in Gilda Brook roundabout within the circulatory lanes 41 HBIs were recorded in two-year period and total AADT in that roundabout is 53234; so a 1% change in AADT (to 53766) leads to 1.6% change in HBIs (i.e. 41.656 HBIs). In addition, if taking the average AADT and average HBI within circulatory lanes see Table 3-9b for the average values, a 1% increase in AADT leads to only an increase of 0.30 in average numbers of HBIs. Therefore, this effect is small and can be considered unimportant.

Signalisation and the two-lane indicator are associated with lower numbers of HBIs, but were found to be insignificant regarding total and truck accidents. Note that the marginal effect indicates that the influence of the two-lane indicator (-3.75) and the signalised indicator (-0.17) are not high within the two-year period; based on these figures these effects can be considered relatively unimportant.

Un-signalised roundabouts are associated with lower total and truck accident numbers, and HBIs. In addition, within circulatory lanes, the marginal effect indicates that the influence of ICD on total accidents (0.83), truck accidents (0.23), and HBIs (0.3) are low and can be considered unimportant.

As the majority of factors associated with more/fewer truck and total accidents within circulatory lanes are similar to those associated with more/fewer HBIs (compare last two columns of Table 8-2), it can be concluded, once again, that considering truck HBIs can be useful in identifying locations of high accident risk.

8.2.3 At Approaches

Table 8-3 illustrates the effect of each traffic and geometric variable on total accidents, truck accidents, and HBIs but this time only considering the data at approaches. Traffic level, ln(AADT) was found to be highly significant in estimating levels of total and truck accidents and truck HBIs.

Table 8-3 indicates that a higher percentage of truck traffic at approaches is associated with higher numbers of truck accidents and HBIs, while this effect was found to be insignificant on total accident numbers, probably because the percentage of truck traffic is not high compared to AADT (average truck percentage at approaches is 6.44%). This implies percentage of truck traffic is more important for other vehicles' safety on circulatory lanes than at approaches.

Table 8-3 Effect of Geometric and Traffic Variables on Total Accidents, Truck Accidents, and HBIs at Approaches

Variable	Total accident numbers	Truck accident numbers	HBI numbers
ln(AADT)	↑↑	↑↑	↑↑
Percentage of average annual daily truck traffic	-	↑↑	↑↑
Signalised approaches compared to un-signalised approaches	↑	-	87.5% ↑
Two-lane approaches compared to three-lane approaches	66% ↑	53% ↑	33% ↑
Approaches located on grade-separated roundabouts relative to approaches located at at-grade roundabouts	99.99% ↑	↑	78% ↓
Entry width	-	↑	96% ↑

Note that approaches that are located on grade-separated roundabouts constitute (117) A- and B- class roads and (94) M-class roads and there are a high number of HBIs in A-class approaches, but the majority of HBI numbers were recorded in M-class roads that carry higher traffic volumes. This is this is not the case for total and truck accidents because all approaches that are located at grade-separated roundabouts (A- and M-class approaches) are associated with high numbers of total and truck accidents.

Signalised approaches were found to have an insignificant effect on truck accident numbers, but were found to have significant positive effect on total accident numbers and HBI numbers. The marginal effect indicates that at signalised approaches HBIs and total accidents increase by an average of 1.81 over the 11-years period and 3.87 over the two-year period, relatively, and this is considered low and relatively unimportant given the total number of HBIs and accidents.

According to the marginal effects, entry width associated with higher numbers of truck accidents and HBIs by an average of 0.081 and 0.44, respectively, also indicating its relative unimportance.

Based on the marginal effects, the influence of two-lane approaches on total accident, truck accident, and HBI numbers is small (1.25, 0.057, 5.23, respectively) and, relatively, can be considered unimportant. And for entry width the marginal effect is 0.083 for truck accidents and 0.44 for HBIs and these effects are small and considered to be unimportant.

At approaches, factors influencing truck accident numbers are similar to those influencing HBI numbers with the exception of grade type indicator (compare last two columns of Table 8-3). As such there is a significant similarity between the HBIs and total and truck accidents models, and it can be concluded that HBIs can be used as supplementary information for providing safety analysis at approaches.

8.3 Factors Influencing Total Accidents, Truck Accidents, and HBIs on Grade-Separated and At-Grade Roundabouts

Models were developed for total accidents, truck accidents and HBIs based on type of grade (grade-separated, and at-grade) and the results presented in Chapter Five for total and truck accidents and in Chapter Seven for HBIs. Table 8-4 illustrates the effect of each traffic and geometric variable on total accidents, truck accidents, and HBIs at grade-separated roundabouts.

For grade-separated roundabouts, AADT, the percentage of truck traffic and ICD are all associated with higher numbers of total accidents, truck accidents, and HBIs, although it should be noted that the marginal effect of ICD for truck accidents and HBIs were not high and are considered relatively unimportant, with values of 0.7, and 6.8 for truck accident, and HBI numbers, respectively. However, for total accidents a higher marginal effect (4) was identified over the 11-years period indicating that total accidents at grade-separated roundabouts are associated with ICD.

Table 8-4 Effect of Geometric and Traffic Variables on Total Accidents, Truck Accidents, and HBIs at Grade-Separated Roundabouts

Variable	Total accident numbers	Truck accident numbers	HBI numbers
ln(AADT)	↑↑	↑↑	↑↑
Percentage of average annual daily truck traffic	↑↑	↑↑	↑↑
ICD	↑	↑	↑
Circulatory roadway width	-	↓	-
Entry width	-	-	↑↑
Un-signalised roundabouts compared to partially signalised roundabouts	↓↓	↓↓	49% ↓
Signalised roundabouts compared to partially signalised roundabouts	-	72.5% ↓↓	54% ↓↓
Two-lane roundabouts compared to three-lane roundabouts	-	66% ↓	-
Four-arm roundabouts compared to six-arm roundabouts	60% ↑↑	-	↑↑
Five-arm roundabouts compared to six-arm roundabouts	-	-	↑↑

Across the whole 70 roundabouts, increasing circulatory roadway width was associated with a lowering of truck accident and HBI numbers, while for grade-separated roundabouts this factor was found to be significant only for truck accident numbers. However, the marginal effect for circulatory roadway width was not high and is considered relatively unimportant with a value of -2.4 over the 11-years period. The number of arms was found to be more associated with HBI numbers than circulatory roadway width, and to have an insignificant effect on truck accident numbers. In addition, the influence of entry width on accidents was neutral, the same as for the whole 70 roundabouts, only being significant for HBI numbers.

As the whole 70 roundabouts, un-signalised and signalised grade-separated roundabouts were found to have similar effect on truck accident and HBI numbers.

When grade-separated roundabouts are compared to all 70 roundabouts on the base of the two-lane indicator, it was found that the number of lanes has a similar influence trend on truck accident numbers, but the marginal effect was higher (-3.04) compared than that for all 70 roundabouts (-1.88).

The influence of the four-arm indicator on total accidents was varied across observations the majority of four-arm roundabouts had more total accident numbers, and their influence on HBIs was fixed across the observations and all four-arm roundabouts had more HBI numbers. Five-arm roundabouts had higher numbers of HBIs, but an insignificant effect on total and truck accidents. However, previous studies (Kennedy, 2007; Shadpour, 2012; and Kim et al., 2013) indicate that as the number of arms increase, total accident numbers increase, but note that Kennedy (2007) used the rate of accidents (accident/year) instead of the total number. The DMRB TD 16/07 (2007) recommends only three and four-arm roundabouts, because higher numbers of arms mean more conflict points, and hence such roundabouts are less safe. Note that all grade-separated roundabouts included in this study are four, five, or six-arm roundabouts.

When at-grade roundabouts were analysed separately from grade-separated roundabouts, different results were acquired. Table 8-5 illustrates the effect of each traffic and geometric variable on total accidents, truck accidents, and HBIs at at-grade roundabouts.

Table 8-5 indicates that AADT is associated with higher numbers of total accidents, truck accidents, and HBIs. The influence of the percentage of truck traffic is not clear for the three dependent variables at at-grade roundabouts. A higher percentage of truck traffic is associated with a higher number of HBIs, but was found to be insignificant with regard to truck accident numbers. In addition, half of the at-grade roundabouts had more total accident numbers with higher percentages of truck traffic, while those locations that had lower total accidents with higher truck percentages were found to be un-signalised, and it is identified that un-signalised roundabouts are associated with lower accident numbers and rates. The marginal effect indicates that the influence of the percentage of truck traffic on HBI proportion (15.7%) is much higher than their effect on total accident proportion (0.319%). This indicates that as the percentage of trucks increases in at-grade roundabouts the percentage of HBIs increases. In addition, total accident is more closely associated with AADT than the percentage of truck traffic, possibly because there are lower numbers of total accidents relative to HBIs.

Table 8-5 Effect of Geometric and Traffic Variables on Total Accidents, Truck Accidents, and HBIs at At-Grade Roundabouts

Variable	Total accident numbers	Truck accident numbers	HBI numbers
ln(AADT)	↑↑	↑↑	↑↑
Percentage of average annual daily truck traffic	51% ↑↑	-	↑↑
Un-signalised roundabouts compared to partially signalised roundabouts	↓↓	↓↓	-
signalised roundabouts compared to partially signalised roundabouts	-	-	↑↑
Two-lane roundabouts compared to three-lane roundabouts	-	-	75% ↑↑

For at-grade roundabouts the influence of geometric variables is not the same on total and truck accident numbers and on HBI numbers, probably because at-grade have different geometric design features relative to grade-separated roundabouts, for instance: grade-separated roundabouts are bigger so their geometric parameters are bigger relative to at-grade roundabouts and this probably leads the influence of parameters to be different. In addition, the majority of grade-separated roundabouts are signalised or partially signalised because of the higher amount of traffic and this will also lead to a different influence relative to at-grade roundabouts. However, because of the lower number of observations: only 19 at-grade roundabouts are included in this study, further investigation, including more at-grade locations, is suggested to further explore the effects of geometric parameters on accidents and HBI numbers.

It can be concluded that when grade-separated roundabouts are analysed separately from at-grade roundabouts, different results are acquired compared to when analysing all locations together. Based on the results illustrated in Table 8-4 and Table 8-5, it can further be concluded that HBIs are more appropriate for assessing the safety risks of all types of roundabout together (grade-separated with at-grade), because HBI numbers are influenced in a similar way to total and truck accident numbers by traffic and geometric variables; while for at-grade roundabouts HBI numbers are influenced by geometric variables in a different way to total and truck accident numbers, and the probable reason is due to lower number of observations.

8.4 Discussion, Summary, and Conclusion

This chapter illustrated the main factors influencing truck accidents, total accidents, and HBIs based on the models that were examined and presented in Chapter Five and Chapter Seven. The following paragraphs illustrate the main points identified.

Traffic variables

For whole roundabouts, including for grade-separated and at-grade roundabouts when analysed separately, and for approaches, the increased traffic (expressed as natural logarithm of AADT) leads to higher total accidents, and truck accidents, as expected from a wide range of previous studies. This is also true for HBIs. This is not the case for total and truck accidents on circulatory lanes alone; although the relationship does hold for HBIs (it may be that this is a case where the higher numbers of HBIs has led to traffic being identified as a significant variable where the lower number of total or truck accidents did not). However, based on the regression coefficient, magnitude of the influence of AADT on increasing HBI numbers is small.

Percentage of truck traffic is also associated with higher numbers of total and truck accidents and HBIs for whole roundabouts and for grade-separated roundabouts when analysed separately. This effect was found to vary across whole roundabouts when related to total accidents; those locations found to have lower accidents with higher truck percentage are 8 at-grade roundabouts and this reflects the fact that half of at-grade roundabouts when analysed separately do not show an increase in total accidents as percentage of truck traffic increases. It was also found that at at-grade roundabouts when analysed separately, percentage of truck traffic is not linked to truck accident numbers. However, according to the marginal effect, illustrated in Table 5-9, a 1% increases in truck traffic increase total accidents by 0.32% but this is a small effect, and therefore is considered unimportant. HBIs do increase with percentage of truck traffic for at-grade roundabouts, as expected simply from the level of exposure (as for accidents). A possible reason is that there is a higher number of HBIs (2556) recorded in at-grade roundabouts than there are truck accidents (103). Hence truck accidents are too few to give a reliable analysis and HBIs are a better indicator.

Percentage of truck traffic is a significant variable for total and truck accidents and for HBIs within circulatory lanes. However, the percentage of truck traffic is not a significant variable for total accidents at approaches but remains so for truck accidents and HBIs. It appears from this analysis, therefore, that trucks have a greater impact on other vehicle accidents in circulatory lanes rather than at approaches.

Geometric Variables

a) Inscribed circle diameter (ICD)

ICD statistically highly influences total accident, truck accident, and HBI numbers within circulatory lanes and at grade-separated roundabouts. This effect was found to be insignificant for HBIs at whole roundabouts, while statistically higher ICD was associated with a higher number of total and truck accidents at whole roundabouts. However, the marginal effect indicates that its effect is small on total and truck accident numbers over the 11-year period and, relatively, can be considered unimportant.

b) Circulatory roadway width

Higher circulatory roadway width results in fewer truck accident and HBI numbers for whole roundabouts and is associated with a decrease in truck accident numbers at grade-separated roundabouts. This is not the case for total accidents and HBIs at grade-separated roundabouts, but the marginal effect for truck accidents is low and, relatively, is considered unimportant.

c) Entry width

At whole and at grade-separated roundabouts, higher numbers of HBIs were recorded with higher entry width. However, this effect was found to be insignificant for total and truck accident numbers at whole roundabouts, but previous studies such as that by Retting (2006) state that roundabouts are less safe with higher entry width, and Kim et al. (2013) have found that total accident numbers increase with increasing entry width. At approaches, more truck accidents and HBIs were recorded with higher entry width, while this was not the case for total accident numbers, but the marginal effect for HBIs and truck accidents is low and is also considered unimportant.

d) Signalised or un-signalised

The majority of the signalised whole and grade-separated roundabouts have lower truck accident numbers and half of them also have fewer HBI numbers. On the other hand, the signalised indicator was found, statistically, to be insignificantly related to total accident numbers at whole and at grade-separated roundabouts.

Half of the signalised circulatory lanes have lower numbers of HBIs, while this was not so for numbers of total and truck accidents. However, the average marginal effect for HBIs was low over the two-year period and is considered unimportant. The majority of signalised approaches have more total accidents and more HBIs (although this is not the case for truck accidents). Nevertheless, the values of the marginal effect for total accidents and HBIs were found to be small and are considered unimportant.

When analysing at-grade locations, all signalised at-grade roundabouts were associated with higher numbers of HBIs, while this was not the case for total and truck accident numbers. In this study because only two at-grade roundabouts were found to be signalised, possibly more observations, including more signalised at-grade roundabouts, might had to a different result.

The un-signalised whole roundabouts and un-signalised grade-separated roundabouts were associated with lower numbers of total and truck accidents, while half of them were associated with lower numbers of HBIs. As discussed earlier, having braking data from all trucks travelling within the UK roundabouts might lead to different results if driver behaviour is a factor.

All un-signalised circulatory lanes are associated with fewer numbers of total accidents, truck accidents, and HBIs. The lower number of these events is almost certainly due to lower AADT in un-signalised roundabouts compared to signalised and partially signalised roundabouts.

When analysing at-grade roundabouts separately, all at-grade locations are associated with lower total and truck accident numbers when un-signalised, but this was not the case for HBIs.

e) Number of lanes

The majority of whole roundabouts and grade-separated roundabouts have lower numbers of truck accidents when approaches are two-lane, while this was not the case for total accident and HBI numbers. However, according to the marginal value this effect can be considered unimportant.

For accidents and HBIs within the circulatory lanes, the two-lane approach indicator was found to be unrelated to the numbers of total and truck accidents. The majority of circulatory lanes that are two-lane have fewer HBI numbers, but the marginal effect is low and can be considered, relatively, unimportant.

The majority, half and a quarter of two-lane approaches have greater numbers of total accidents, truck accidents, and HBIs, respectively, than other three-lane approaches. The marginal effect, however, is small and can be, relatively, considered unimportant.

f) Grade type indicator at approaches

The majority of approaches that are located at grade-separated roundabouts have higher total accident and truck accident numbers, while the majority of them are associated with fewer HBIs. The probable reason is due to the higher number of HBIs recorded in M-class approaches rather than in A-class approaches.

g) Number of arms

Five and four-arm grade-separated roundabouts have higher numbers of HBIs than experienced at six-arm grade-separated roundabouts, and 60% of four-arm grade-separated roundabouts have more total accident numbers than observed at similar roundabouts with other number of arms. The number of arm indicator had an insignificant relationship with truck accident numbers for grade-separated roundabouts.

At three-arm roundabouts and half of the three-arm roundabouts, there were fewer truck accidents and fewer HBIs, respectively, when considering whole roundabout events. However, this effect was found to be insignificant on total accidents at whole roundabouts, even though previous studies (Kennedy, 2007; Brude and Larsson, 2000) have found that three-arm roundabouts are associated with lower rates of total accidents.

Summary

Table 8-6 summarises the findings given above by listing those traffic and geometric variables that have a similar relationship to both accident and HBI numbers, grouped by roundabout category.

When at-grade roundabouts are analysed separately from grade-separated roundabouts, only traffic variables were found to have a similar effect on accident and HBI numbers (see Table 8-6), probably because the number of observations for at-grade roundabouts is not enough to make any conclusion about geometric factors based on these results, so it is recommended that more investigation be undertaken to identify if there is a similar influence of the other parameters studied on the number of accidents and HBIs.

Table 8-6 Similar Effects of Traffic and Geometric Variables on Accident and HBI Number

Variable	Roundabout category				
	Whole Roundabout	Within circulatory lanes	Approaches	Grade-separated	At-grade
ln(AADT)	✓		✓	✓	✓
% Truck	✓	✓	✓	✓	✓
Un-signalised roundabouts	✓	✓		✓	
Signalised roundabouts	✓		✓	✓	
Three-arm roundabouts	✓				
Four arm roundabouts				✓	
Circulatory roadway width	✓	✓			
ICD		✓		✓	
Two-lane approaches			✓		
Entry width			✓		

It can be concluded that HBIs are influenced by traffic and geometric variables in a similar way to total and truck accidents (see Table 8-6). It is concluded that HBI records can be used as a surrogate variable for accident numbers, they are a source of much more numerous data than accidents, and this may be important in considering changes or trends in accident risk over a much shorter time than for accidents. The most important variables were AADT and percentage of truck traffic which were found to have a positive influence on accidents and HBIs. Regarding the geometric variables, signalisation, circulatory roadway width, number of arms, and the two-lane indicator are considered the most important factors influencing accidents and HBIs. Chapter Ten considers accident models including HBI numbers as input variable.

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Chapter 9 Design Considerations

9.1 Overview

In the UK, roundabouts are commonly used as a high traffic volume junction. This has led to the construction of large roundabouts with high ICD and results in a high circulating speed. Two points are important and should be considered by design organisations during roundabout rehabilitation and safety improvement (DMRB TD 16/07, 2007):

- the need to consider the geometry of each part, and
- the need to review the existing roundabout marking

For the present study, road markings, truck apron, and shape of the central island were investigated using the Google tool in order to check if these configurations have any effect on accident and HBI occurrences beside the influence of geometric and traffic variables, so as to enhance the study results with these requirements and make further recommendations. In this section, based on the results of this study illustrated in Chapter Five to Chapter Seven, the design elements of the selected study are checked and compared with the geometric design principles illustrated in the DMRB TD 16/07 (2007). In addition, road markings identified in this study are compared with the DMRB TA/78 (1997) in order to make further recommendations based on markings if necessary. The following paragraphs consider possible design solutions for the worst situations investigated based on accident and HBI records, followed by a summary in the end of the Chapter.

9.1.1 Inscribed Circle Diameter (ICD)

As illustrated in Section 2.3.3, when a roundabout is at-grade the ICD should not be >100m (DMRB TD 16/07, 2007) as this will increase the speed within the circulatory lanes. The location A1237/A64 is signalised, at-grade and is a three-arm roundabout without truck apron shown to have an ICD of 133m which is greater than the design limit (100m). In A1237/A64, 62 (with predicted value of 50.5), 9 (with predicted value of 6.4), and 59 (with predicted value of 54) total accidents, truck accidents, and HBIs were recorded. Chester Rd. is an at-grade un-signalised roundabout with a diameter of 119m but has recorded low accident numbers; this roundabout has an irregular shaped central island which leads to have a higher notional ICD. The rate of total and truck accidents in this roundabout is not high: 11 (with predicted of 15), 0 (with predicted of 1) for total and truck accidents, respectively. However a high numbers HBIs were recorded: 251 (with predicted of 218) and the probable reason was not the diameter, because this roundabout is located on the A5 with a high percentage of truck traffic: 10%.

9.1.2 Entry Width

Based on DMRB TD 16/07 (2007) the maximum entry width for multi-lane roundabouts is 15m because a higher entry width is associated with higher traffic volume as stated by Kimber (1980). For the whole roundabouts entry width is averaged over all arms, and based on this the maximum width is 15 m which is within the limit of design. Some individual approaches, show an entry width of >15m, these are illustrated in Table 9-1. Note that the majority of wide approaches are located on M roads.

Table 9-1 Approaches with Entry Width of Greater than 15m

Junction	Approaches	A- or M- class roads	Total accident (predicted)[37]	Truck accident (predicted)	HBI (predicted)	Entry width	AADT
J21 On M1	west	A	29 (20)	12 (5)	35 (62)	16.55	33722
J28 On M1	south	M	14 (14)	1 (4)	100 (100)	16.20	21358
J13 On M4	north	A	13 (16)	3 (6)	110 (142)	16.80	26785
J19 On M6	east	M	4 (10)	1 (2)	3 (6)	15.60	13796
J40 On M6	west1	A	11 (10)	7 (5)	21 (46)	17.40	13087
J40 On M6	west2	A	4 (10)	3 (2)	1 (4)	16.10	13198
J3 On M27	north	M	26 (18)	11 (7)	251 (290)	16.90	29893
J2 on M40	west	M	3 (3)	1 (1)	2 (2)	20.00	2460

Based on modelling results, entry width has insignificant effect on total accidents, but their effect varied across observations for truck accident and HBIs. The majority of approaches associated with higher truck accidents and HBIs had higher entry width. Extending the splitter island is one way of reducing entry width for locations with poor accident records. Another is using coloured or textured surfacing or using hatched marking (DMRB TD 16/07, 2007). So the approaches listed in Table 9-1 require extending the splitter island using kerbs or marking. Note that AADT in the west direction of J2 on M40 is low relative to the other locations illustrated in Table 9-1 and also to the other approaches studied. In addition to this

[37] Predicted value from the resulted random parameters model

approach, there are a number of approaches with an AADT of less than 5000 and with entry widths of >10m. Based on the modelling results in this study it was found that higher entry widths are associated with higher truck accidents and HBIs at approaches, so care should be taken for locations with low traffic volumes and high entry widths.

However, for designing new roundabouts as illustrated in Section 2.3.3, DMRB TD 16/07 (2007), usually the design year flow is considered (i.e. higher entry widths for the future), but when the roundabout is constructed, for the early years of service, it may be necessary that the designer should consider a temporary stage (e.g. use a colour or textured surface in the early stage of service).

9.1.3 Shape of Central Island

Kennedy (2007) shows that the majority of the roundabout design guidelines advise using circular roundabouts, yet the majority of other types of intersections when converted become non-circular roundabouts. In this study there are 43 oval-shape central island roundabouts, and 27 circular shape roundabouts. Table 9-2 illustrates the rates of actual and predicted value of total accidents, truck accidents, and HBIs per roundabout with respect to oval shape and circular shape roundabouts. It is clear that the rates of total accidents, truck accidents, and HBIs are higher in oval shaped rather than circular shaped roundabouts. The probable reason for having this result is 42 out of 43 of the oval shape roundabouts are grade-separated. The rate of total accidents, truck accidents, and HBIs at grade-separated roundabouts is higher relative to these rates at at-grade roundabouts. In addition they have higher AADT as reported in Table 9-2; oval shape roundabouts have higher AADT by 41% relative to circular shape roundabouts. This result is in line with Alphand et al. (1991b) although their result was for total accident rates. In addition, Rodegerdts et al. (2010) concluded that a circular shape is safer because they encourage a constant speed with the circulatory lanes; while oval roundabouts increase the speed in the straight line then induce speed to decrease while the vehicle approaches the arc, which precipitates loss of control accidents within circulatory lanes.

Table 9-2 Central Island Shape Type

Shape type	Roundabout no.	Total accident		Truck Accident		HBI		AADT per roundabouts
		No.	Rate	No.	Rate	No.	Rate	
Oval	43	3315 (3238)	77 (75)	811 (782)	19 (18)	7406 (7787)	172 (181)	60543
Circular	27	919 (924)	34 (34)	176 (181)	7 (6.7)	3278 (2984)	121 (110)	35388

9.1.4 Truck Apron

As illustrated by DMRB TD 16/07 (2007), a truck apron is used for small roundabouts so that heavy vehicles can cross the circulatory lanes safely. The set of roundabouts considered in this study included 19 at-grade roundabouts and they were considered small compared to grade-separated roundabouts. For the 19 selected locations only three roundabouts have truck aprons. These roundabouts are B6326/A46, B6166/A46, and A46/A17. In these locations the rates of total accidents, truck accidents, and HBIs are 90, 20, and 176, respectively, (predicted value of 68, 15, and 167, respectively); while for the other 16 locations without truck apron the rate is 16, 2.0, and 107, respectively (predicted value of 21, 2.8,79, respectively). This indicates that availability of truck aprons in the three small roundabouts has no effect on reducing accidents as stated by DMRB TD 16/07 (2007). Note that the percentage of trucks in these locations is high (9-10 %) and, probably because these locations have enough space (circulatory width of >10m) for trucks to negotiate the roundabouts, they do not use the truck aprons leading to a higher rate of truck accidents and HBIs being recorded in these locations. Gingich and Waddell (2008) have found that during morning and evening peak periods 77% of trucks did not use truck aprons.

9.1.5 Circulatory Roadway Width

According to DMRB TD 16/07 (2007), illustrated in Section 2.3.3, the circulatory roadway width must be 1 to 1.2 times the maximum entry width. As stated, maximum entry width is 15m and in that case the maximum circulatory roadway width must be between 15 to 18m. The circulatory roadway width for the selected locations is in the range of 7 to 15m and this indicates that the width is within the design limitations. For large roundabouts the width of the circulatory lane can be reduced by adding a kerb to the splitter island. In addition, this decrease can be achieved physically using coloured surfacing or hatched marking (DMRB TD 16/07, 2007). However, based on the modelling results, higher circulatory roadway width is associated with lower truck accident and HBI numbers, possibly because higher width allows trucks to manoeuvre more safely through the roundabouts. It was found that circulatory roadway width, statistically, is not associated with total numbers of accidents, maybe because the width is always far greater than that required for safe car manoeuvrability so has no effect on total accident occurrences.

9.1.6 Road Marking

DMRB TD 16/07 (2007) states that road marking should be considered as an essential part of the design process as this affects safety and traffic volume of the roundabouts. As data is available for accidents for 11 years and for HBI for two-years, it is important to investigate how road marking changed through the selected 70 roundabouts. This will help make further recommendations based on the available road markings. Because, road marking regulates flow for roundabouts that their traffic flow has been changed since design, improves safety, smooth flow for roundabouts with irregular geometry (DMRB TD 16/07, 2007). Road markings were investigated for the selected 70 roundabouts using Google earth. Accident and HBI rates were identified for each type of marking and the results are reported in Table 9-3.

Table 9-3 Road Marking Type with the Rates of Total Accident, Truck Accident, and HBIs for the Selected Locations

Marking type	Roundabout no.	Total accident (predicted)		Truck accident (predicted)		HBI (predicted)	
		No.	Rate	No.	Rate	No.	Rate
Concentric	16	1006 (942)	63 (58)	218 (206)	14 (13)	2262 (2283)	141 (143)
Partial concentric	15	916 (896)	61 (60)	188 (189)	13 (13)	2429 (2620)	162 (174)
Concentric spiral	16	1420 (1450)	89 (91)	403 (388)	25 (24)	2793 (3261)	175 (203)
Spiral	11	676 (625)	61 (57)	150 (146)	14 (13)	1891 (1443)	172 (131)
Non	12	216 (249)	18 (21)	28 (33)	2 (3)	1309 (1164)	109 (97)

Five of the roundabouts with concentric markings are five and six-arms, with accident rates of 78, and the other eleven roundabouts with concentric markings are three and four-arm roundabouts with accident rates of 56. Since concentric-spiral and spiral markings are more suitable for big roundabouts (DMRB TA 78/97, 1997) it is necessary to re-assess the big roundabouts that have concentric markings and change these markings in order to make the path within the roundabouts more efficient for the users, and thereby reduce any accidents that might occur because of insufficient marking within the roundabouts.

Roundabouts with concentric spiral markings are associated with a higher rate of total accidents, truck accidents, and HBIs. The rates of total and truck accidents for concentric and spiral type marking are nearly similar, followed by partial concentric marking. For HBIs spiral markings are associated with the highest rates relative to partial concentric and concentric type roundabouts. However, for the three types of events those roundabouts with no markings recorded the lowest rates. Note that five of the roundabouts that have no markings within the circulatory lanes are grade-separated and the rate of total accidents and truck accidents are 25 and 3.4, respectively; while in the other 7 at-grade locations with no marking the rate of total accidents and truck accidents is lower (13 and 1.57, respectively). This indicates that these grade-separated roundabouts require marking within the circulatory lanes. In addition, the rate of HBI in 7 at-grade locations with no marking is much higher relative to the five grade-separated locations with no marking, 169 (predicted value is 141) relative to 25 (predicted value is 35), and probably (based on the results of this study in which the factors influencing HBIs have been found to be similar to those influencing accidents) these rates might indicate future accident risk. Therefore, it can be concluded that markings are necessary for these 7 locations because of the high HBI rate. Note that when comparing grade-separated roundabouts with no marking to similar roundabouts with markings, it was found that grade-separated roundabouts recorded a lower rate of HBIs of 25 (35 is the predicted value), relative to a rate for grade-separated with markings of 174 (182 is the predicted value). At-grade roundabouts with no marking recorded a higher rate of HBI of 169 (141 is the predicted value), relative to a rate for at-grade roundabouts with markings of 114 (103 is predicted value).

Regarding the roundabouts that have spiral markings, four of them are small roundabouts located at at-grade. Based on DMRB TA 78/97 (1997) spiral markings are suitable for big roundabouts. Comparing these three at-grade locations to the other 8 roundabouts with spiral marking, a similar rate of total accidents (59 relative to 62) was recorded and a higher truck accident rate (16 relative to 13), in addition to a similar HBI rate (173 relative to 171). These three at-grade roundabouts probably require re-assessment regarding marking.

9.1.7 Signalisation

Having accidents because of high ICD on large roundabouts illustrates that signalisation is required (DMRB TD 16/07, 2007). However, in this study signalised circulatory lanes have the highest rate of accidents and HBIs followed by partially signalised circulatory lanes, and un-signalised circulatory lanes have the lowest rate of accidents and HBIs. Based on the modelling results un-signalised circulatory lanes are associated with a lower number of accidents and HBIs. Signalised circulatory lanes have no effect, statistically, on accidents, but half of the roundabouts that are signalised within the circulatory lanes are associated with lower HBI numbers. Based on the modelling results, at approaches signalisation is associated with higher total accident and HBI numbers. The fact that signalised roundabouts have a higher rate of accidents and HBIs is not because signalisation is the cause of these events, but probably because signalisation is installed in these locations because of high traffic volume and this is the primary cause of these accidents. Also, the majority of the roundabouts studied have high ICDs and some of them are partially signalised. Therefore, it is recommended to re-assess partially signalised roundabouts, in order to signalise the locations that require traffic control and, hence, to improve traffic safety.

9.2 Summary

This chapter illustrated the design considerations for the main factors influencing truck accidents, total accidents, and HBIs. Based on the design considerations, all the selected locations have circulatory roadway widths within the design limit, a higher width being associated with lower numbers of truck accidents and of HBIs. Probably larger width allows safer manoeuvrability because of truck size.

Some locations have high entry width with low traffic volumes; based on modelling results higher entry width is associated with higher truck accidents and HBIs at approaches, so it is important to reduce this width, physically, using a coloured, or textured surface or by adding a kerb to the splitter island. In modelling results all un-signalised roundabouts and the majority of signalised roundabouts were associated with lower numbers of accidents and HBIs compared to partially signalised roundabouts. ICD has a greater influence on accidents and HBIs in grade-separated roundabouts. For this reason, for the locations with high ICD and which are partially signalised, it is recommended to fully signalise as this will regulate the traffic both from approach and within circulatory lanes.

For the selected locations only three of the roundabouts have truck aprons and the rate of truck accidents and HBIs are high in these locations. This may be because these trucks do not use truck aprons, as found by Gingich and Waddell (2008), 77% of trucks do not use truck aprons. Addition of truck aprons in these roundabouts does not reflect the safety improvement.

Oval shaped roundabouts have a higher rate of actual and predicted total and truck accidents and HBIs relative to those of circular shape of roundabouts probably because all the oval shapes are big roundabouts.

Based on DMRB RD 16/07 (2007) big roundabouts require spiral and spiral-concentric markings, while small roundabouts require concentric markings. In this study regarding road marking, some big roundabouts have simple concentric marking and are recorded as having high accident and HBI rates (actual and predicted). Big roundabouts require concentric-spiral or spiral marking for improved safety. In addition, spiral markings are recommended for big roundabouts and some of the small roundabouts compared to big roundabouts have spiral markings and recorded high rates of actual and predicted accidents and HBIs and these locations may require a concentric marking in order that the movement path is easier for the roundabout users.

Chapter 10 Relationship Between Total Accidents, Truck Accidents, and Harsh Braking Incidents along with Traffic and Geometric Variables

10.1 Overview

As concluded in Chapter Eight, HBIs are influenced by traffic and geometric variables in a similar way to total and truck accidents. So, as a further step it is important to consider any relationship that may exist between accident numbers and HBI numbers. In this chapter, models are identified for total and truck accident numbers for different roundabouts and approach categories using HBI numbers as an independent variable along with traffic and geometric parameters. As described in the methodology (Section 3.3.1), the selected locations include three, four, five and six-arm roundabouts, either grade-separated or at-grade, with approaches located on A roads, B roads, or M roads, and are either signalised, or un-signalised, so it is important to explore how total and truck accidents are related to HBIs based on the available geometric cases mentioned. In addition, in order to identify whether HBIs can be used to help predict accidents, the relationships between the two for the whole roundabout, within the circulatory lanes, and at approaches, for different grade separations, and for different types of approach are explored and illustrated in the following subsections. It is important to explore if HBIs can be used as an independent variable along with the traffic and geometric parameters to predict accidents at roundabouts, and, thereby, to identify locations at high risk of accidents. HBIs occur at a higher rate than accidents, so it is possible that such data could help to identify the locations that have safety risks. A discussion is then used to compare the estimated models that used HBIs with those without HBIs as input variable. The final section provides the summary and conclusion for the chapter.

10.1.1 Relationship Between Total and Truck Accidents and HBIs for Whole Roundabouts

Figure 10-1 illustrates the relationship between total and truck accident numbers and HBI numbers for the selected 70 roundabouts. The R^2 between accidents and HBIs is low, but a linear test between the two indicates that there is a statistically significant linear relationship between total accidents and HBIs (F (1, 68) = 13.157, p-value<0.01). In addition, a significant linear relationship was identified between truck accidents and HBIs (F (1, 68) = 9.048, p-value<0.01). This indicates that for whole roundabouts as the number of HBIs increases, total and truck accidents also increase. However, from a practical point of view, R^2 is small, which means that the relationship between the two is not linear.

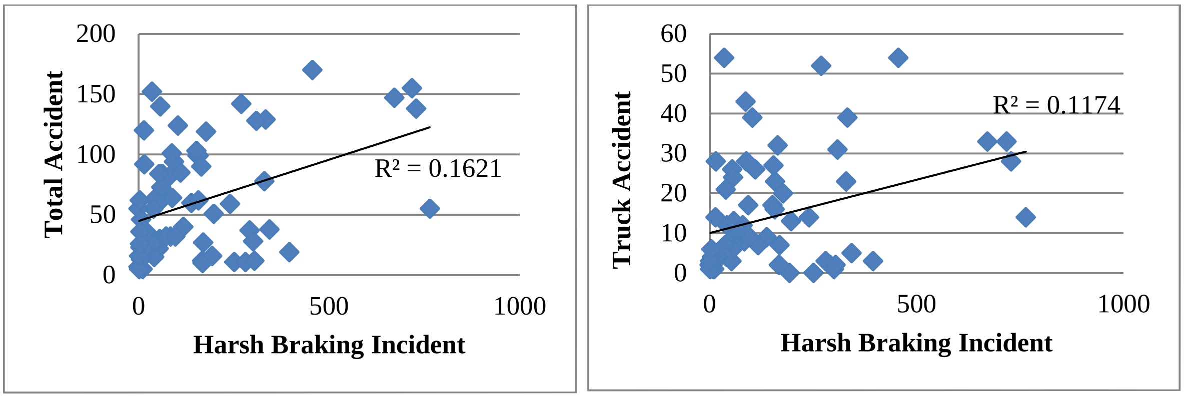


Figure 10-1 Relationship Between Total Accidents and HBIs (left) and Between Truck Accidents and HBIs (right) for Whole Roundabouts

Accident data is count, non-negative, and discrete, and a NB model is best for predicting this kind of data. For this reason, both a random and a fixed-parameters NB model were applied to total and truck accident numbers in order to explore whether HBIs can be used along with geometric and traffic variables to predict total and truck accident numbers for the selected 70 roundabouts. Table 10-1 presents the estimated results for total and truck accidents at whole roundabouts. There is a relationship between numbers of total accidents and HBIs with geometric variables as illustrated in Table 10-1, but when traffic variables are added to the estimated model shown in Table 10-1, the numbers of HBIs becomes an insignificant independent variable.

Table 10-1 Total and Truck Accident Correlation with HBIs and Geometric Parameters

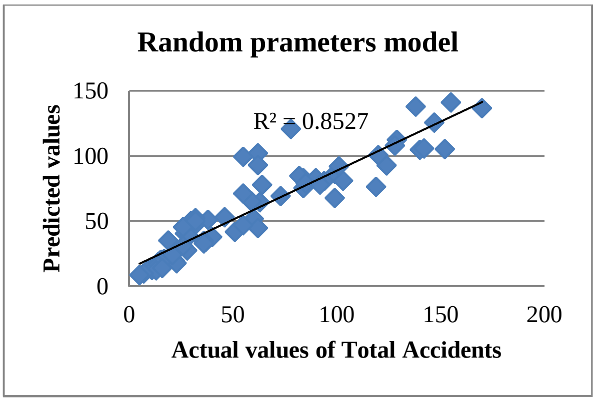
Independent Variable	Random parameters NB model for total accident with geometric and HBI variables		Fixed parameters NB model for truck accident with only HBIs as independent variable	
	Coefficient	*t*-stat	Coefficient	*t*-stat
Constant	3.93	19.621***	2.3067	13.605***
HBI	0.0006	2.243**	0.002	1.857*
Three-arm indicator	-0.77	-2.330**		
ICD	0.0025	2.869***		
Un-signalised indicator	-0.789	-6.153***		
SD	0.442	5.439***		
Four arm indicator	-0.234	-2.239**		
SD	0.343	4.947***		
Signalised indicator	-0.059	-0.513		
SD	0.324	3.523***		
Log-likelihood at convergence	-321.0681		-266.2470	

* At 90% significance level ** At 95% significance level *** At 99% significance level

Figure 10-2 (left), illustrates a comparison of the actual values of total accidents to the predicted values based on harsh braking data and geometric variables: it is clear that the input variable leads to a good prediction of accidents based on the identified R^2.

With an even-increasing number of instrumented vehicles, it is desirable to see whether an-vehicle instrumentation could replace specifically collected traffic data. Therefore, this model was compared to the model identified for total accidents at whole roundabouts without using HBI as input variable (see Table 5-4), using AIC (Eq. 3-14) as the measure.

As discussed in Section 3.5.3, the lower the AIC, the better the fit of the model; and it was found that AIC for the model without HBI is lower than with HBI as an input variable (644.188 versus 656.136, respectively). In addition, comparing Figure 10-2 (left) with Figure 5-1 (left) for total accidents without having HBIs but including traffic (AADT and truck percentage instead) as an input variable has a slightly better prediction. Hence, where continuous traffic data records are not available a fairly immediate and responsive assessment of accident probability is likely to come from HBI (together with site-specific geometry). This indicates that for whole roundabouts, the input variable HBI is not a useful replacement of AADT and the percentage of truck traffic inputs. This indicates that traffic variables at whole roundabouts are important, and more significant than HBIs.



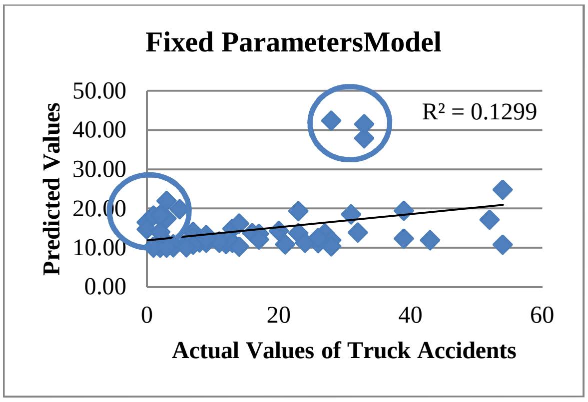


Figure 10-2 Predicted Value vs Actual Value of Total Accidents (left) and of Truck Accidents (right) for Whole Roundabouts

A significant fixed NB model was identified when truck accidents were related to HBIs. The resulting model is (see Table 10-1):

$$Truck\ accident = 10 \times e^{0.002\ incident} \tag{10-1}$$

It can be seen that a high constant value was identified for truck accidents for the whole roundabouts, implying that when there are few HBIs the number of truck accidents will still be high. Figure 10-2 (right), illustrates the correlation between actual values and predicted values, from which it is clear that the influence of HBIs as the only variable is probably the reason that the model is biased[38], and as a result gives a poor prediction of truck accidents. The three outlier points in Figure 10-2 (right) are J3 on M27 (M27/M271), J2 on M6 (M6/M69), and J28 on M1. They are partially and fully signalised grade separated, and are busy junctions. Therefore, they recorded higher truck accident numbers relative to the other locations outlined in the Figure 10-2 (right) which relate to at-grade, un-signalised roundabouts with lower traffic level and lower numbers of truck accidents. Therefore, it is clear that a good model must include these parameters as inputs.

Total and truck accidents were normalised by total and truck traffic, respectively, in order to identify if there is a relationship between normalised accidents and HBIs. It was found that HBIs are insignificant when related to normalised total and truck accidents, either alone or with geometric variables. The implication of having a normalised model including HBI and geometric variables as independent variable is to get a better overall fit model for total and truck accidents at whole roundabouts.

10.1.2 Relationship Between Total and Truck Accidents and Harsh Braking Incidents Within Circulatory Lanes

Figure 10-3 illustrates the linear relationship between total and truck accidents with HBIs within the circulatory lanes. In Chapter 6, Table 6-1, it was found that only 13% of HBIs occurred within the circulatory lanes, while 32% and 36% of total and truck accidents, respectively, occurred within the circulatory lanes, resulting in a low R^2 value between accident and HBI numbers. ANOVA results indicate that, statistically, there is a significant linear relationship between total accidents and HBIs (F (1, 68) = 8.289, p-value<0.01) and that there is, statistically, a significant linear relationship between truck accidents and HBIs (F (1, 68) = 24.494, p-value<0.01): as HBIs increase, the number of total and truck accidents increase. However, as for whole roundabouts, from a practical point of view the low value of R^2 indicates that the relationship between the two is not linear at all times for the selected locations.

[38] When there is a large and systematic difference between actual value and predicted value the model is termed biased. For a perfect unbiased model, the difference between actual value and predicted values should be zero.

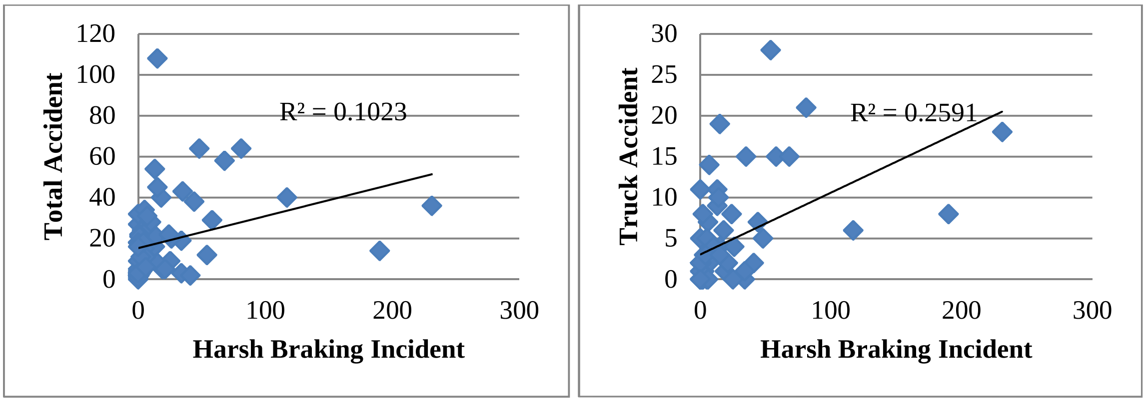


Figure 10-3 Relationship Within Circulatory Lanes Between Total Accidents and HBIs (left) and Between Truck Accidents and HBIs (right)

Therefore, a random and a fixed NB model were used to identify the influence of HBIs, along with traffic and geometric variables, on total and truck accidents within the circulatory lanes and the results are presented in Table 10-2.

Table 10-2 Relationship Between Total and Truck Accidents Within Circulatory Lanes

Independent Variable	Fixed parameters NB model for total accident with percentage of truck traffic and HBI as independent variables		Fixed parameters NB model for truck accident with AADT and HBI as independent variables	
	Coefficient	*t*-stat	Coefficient	*t*-stat
Constant	2.18	7.773***	-5.49	-1.55
HBI	0.009	2.147**	0.011	1.765*
Truck %	0.058	1.919*	-	-
AADT	-	-	0.611	1.807*
Log-likelihood at convergence	-266.2470		-166.7174	

* At 90% significance level ** At 95% significance level *** At 99% significance level

Only fixed-parameter models[39] were identified within the circulatory lanes, and it was found that HBIs with traffic variables influence the occurrence of total and truck accident numbers. Based on the results illustrated in Table 10-2, the following model was developed for total accident numbers within the circulatory lanes:

$$Total\ accident = 8.84 \times e^{0.009\ incident + 0.058\ truck\ percentage} \quad (10\text{-}2)$$

Within the circulatory lanes, the model identified for total accidents (see Table 5-4) without using HBI as input variables gives a lower AIC (490.8536) than the AIC (538.949) of the model illustrated in Table 10-2 for total accidents (i.e. when HBI is included as an input

[39] HBIs and all the traffic and geometric variables were checked to see if they were randomly distributed across the observations but all the geometric variables were found to have, statistically, insignificant effect, and the influence of traffic and HBI was found to be fixed across the roundabouts.

variable). The lower AIC means the better overall fit of the model, therefore, the model without HBI is better than the model including the HBI as an input variable. This indicates that within circulatory lanes, geometric variables have a larger impact on total accidents than HBIs.

Note that adding any geometric variables to the resulted model of Eq. (10-2) HBI makes insignificant difference as indicated by t-stat (i.e. b/St.Er.) circled in blue and illustrated in Table 10-3. Note that as discussed in Section 3.5.2 that any t-stat less than 1.65 considered insignificant. Table 10-3 illustrates the *LIMDEP* software output results when geometric variables and AADT are added to the HBIs and truck percentages: firstly, the model changes from fixed to random, and secondly AADT, in addition to the percentage of truck traffic, will be significant and the HBI value will be insignificant. This means that geometric and traffic variables within the circulatory lanes have a larger impact on accident occurrences than HBIs.

Table 10-3 *LIMDEP* Output for Total Accidents Within Circulatory Lanes

Variable	Coefficient	Standard Error	b/St.Er.	P[|Z|>z]	Mean of X
Nonrandom parameters					
Constant	-3.10857623	1.87910421	-1.654	.0981	
X1	-.00097802	.00245719	-.398	.6906	18.9571429
X3	.00794016	.00158469	5.011	.0000	158.285714
X5	.30046460	.18674332	1.609	.1076	.30000000
X6	-1.18926480	.23617324	-5.036	.0000	.42857143
X7	.32987505	.17498473	1.885	.0594	10.6752857
X8	.08541081	.02275950	3.753	.0002	6.97428571
Means for random parameters					
X2	.55732193	.21069757	2.645	.0082	.57142857
X4	.01728030	.05395945	.320	.7488	10.6508571
Scale parameters for dists. Of random parameters					
X2	.68794143	.09210170	7.469	.0000	
X4	.02682845	.00665844	4.029	.0001	
Dispersion parameter for NegBin distribution					
ScalParm	4.97355035	1.37355816	3.621	.0003	

where:
x1 is the HBIs, x2 is the two-lane indicator, x3 is the ICD, x4 is the circulatory roadway width, x5 is the signalised indicator, x6 is the un-signalised indicator, x7 is ln(AADT), and x8 is the percentage of truck traffic.

In Eq. (10-2), a high constant value was identified which gives a high predicted value for total accidents even if the other parameters are considered low or zero, and as indicated in Figure 10-4 (left), a poor relationship was identified between actual and predicted values.

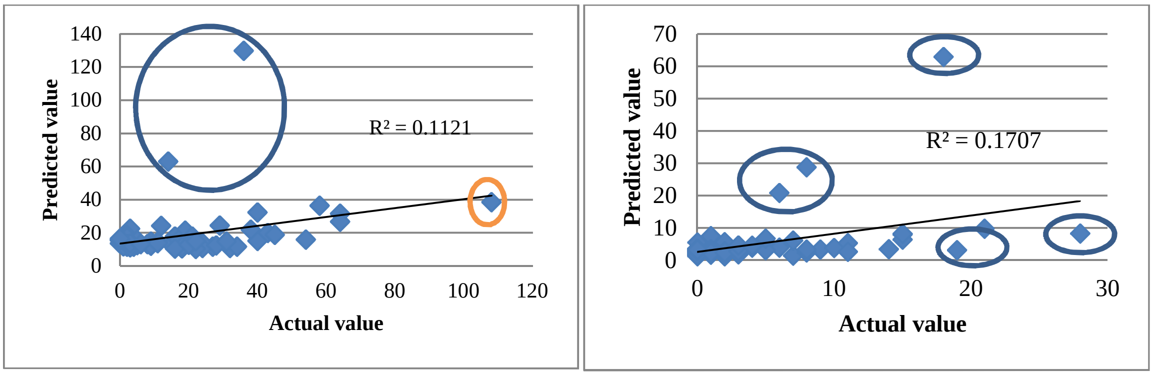


Figure 10-4 Predicted Value Within Circulatory Lanes vs Actual Value of Total Accidents (left) and of Truck Accidents (right)

For the outlier in the orange circle (see Figure 10-4 (left)) a Cook's distance[40] test was undertaken in order to determine whether this observation is influential. As a rule of thumb if the Cook's distance of the associated value exceeds the cut-off value of (4/number of observations) then it is considered too influential (Nieuwenhuis et al., (2012), Van Der Meer et al. (2010), Belsley et al. (1980)). The cut-off value of Cook's distance for 70 observations is of 0.057; when the Cook's distance for the observations is plotted against the number of observations (see Figure 10-5), it is clear that the outlier, which is found to have a value 0.718, should be removed from the model.

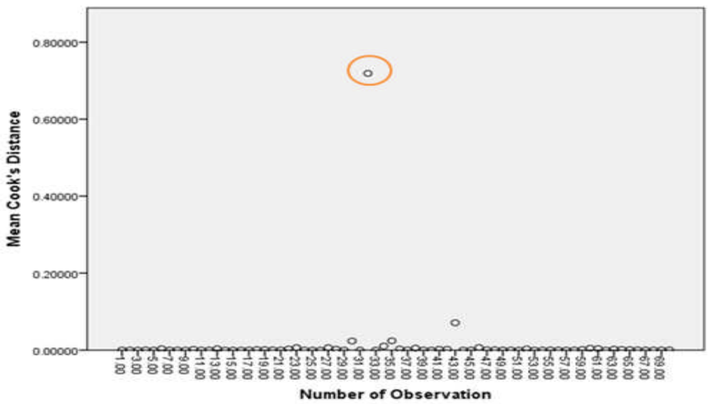


Figure 10-5 Resulted Cooks Distance for the Selected Locations within Circulatory Lanes

Removing all outliers illustrated in Figure 10-4 (left), and re-analysing the data, it was found that the percentage of truck traffic has an insignificant effect on total accident numbers, and only HBIs affect total accident numbers within the circulatory lanes (see Table 10-4). In

[40] "Cook's distance is a measure of the change in the regression coefficients that would occur if this case was omitted, thus revealing which cases are most influential in affecting the regression equation" (Stevens, 1984, p.109).

addition, the predicted value is still not good when it is related to the actual value of total accidents (see Figure 10-6). Adding any geometric variable to the model causes HBIs to become insignificant.

Table 10-4 LIMDEP Output for Total Accidents Within Circulatory Lanes for 67 Roundabouts

```
+---------+--------------+----------------+--------+---------+----------+
|Variable| Coefficient  | Standard Error |b/St.Er.|P[|Z|>z]| Mean of X|
+---------+--------------+----------------+--------+---------+----------+
---------+Nonrandom parameters
 Constant|    2.68281565       .39702966       6.757    .0000
 X1      |     .02591311       .00712547       3.637    .0003   13.2985075
 X8      |    -.05697035       .05170756      -1.102    .2706   6.75089552
---------+Dispersion parameter for NegBin distribution
 ScalParm|    1.12161549       .25973141       4.318    .0000
```

where:

x1 is HBI numbers, and x8 is the percentage of truck traffic, it is clear that *t-stat* for percentage of truck traffic (circled) is less than 1.65 and considered insignificant.

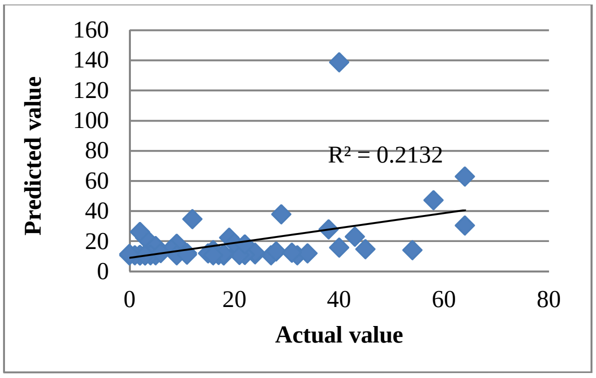


Figure 10-6 Predicted Value with outliers removed vs Actual Value of Total Accidents Within Circulatory Lanes

Based on the results illustrated in Table 10-2, the following model was developed for truck accident numbers within the circulatory lanes:

$$Truck\ accident = 4.1 \times 10^{-3} \times Q^{0.61} \times e^{0.011\ incident} \quad (10\text{-}3)$$

where: Q is the total entry traffic volume.

Within circulatory lanes, the model identified for truck accidents shown in Table 5-10 without using HBI as an input variable gives a lower AIC (314.6026) than that (339.4348) of the model illustrated in Table 10-2 for truck accidents (i.e. when HBI is included as an input variable). This indicates that within circulatory lanes, as for total accidents, geometric variables have a larger impact on truck accidents than HBIs. In addition, a poor relationship was identified when truck accident actual values are compared to predicted values, (see Figure 10-4 (right)), even the resultant models for truck accidents have a low constant value (see Eq. (10-3)). This indicates that geometric variables within the circulatory lanes, as for total accidents, have a larger impact on truck accidents than HBIs.

In order to explore if there is a better prediction, the six outliers were removed from Figure 10-4 (right) and the data re-analysed; it was found that both HBIs and AADT have an insignificant effect on truck accidents within the circulatory lanes, as indicated by the *t*-statistic (see Table 10-5).

Table 10-5 *LIMDEP* Output for Truck Accidents Within Circulatory Lanes for 64 Roundabouts (with outliers removed)

Variable	Coefficient	Standard Error	b/St.Er.	P[|Z|>z]	Mean of X
Nonrandom parameters					
Constant	-2.98582837	3.49873896	-.853	.3934	
X1	.02884169	.01939520	1.487	.1370	9.98437500
X7	.34557880	.33402465	1.035	.3009	10.6173438
Dispersion parameter for NegBin distribution					
ScalParm	.79850496	.22630107	3.529	.0004	

where:

x1 is HBIs, and x7 is ln(AADT).

In addition, as for whole roundabouts, a model was developed within circulatory lanes based on only geometric variables and HBIs, but it was found that HBI have an insignificant effect on total and truck accidents. When total and truck accidents are normalised with the total traffic and truck traffic, respectively, it was found that HBIs are insignificant either alone or with geometric variables.

10.1.3 Relationship Between Total and Truck Accidents and HBIs at Approaches

At approaches, the number of total accidents and truck accidents were related to the number of HBIs; Figure 10-7 illustrates the relationship between them. It is clear according to the value of R^2 that the relationships between them are very different, and this is because the majority of the selected approaches have high numbers of HBIs with lower numbers of accidents. The ANOVA results, however, indicate that there is a significant linear relationship between total accidents and HBIs (F (1, 282) = 16.905, p-value<0.01), and that there is a significant linear relationship between truck accidents and HBIs (F (1, 282) =

10.379, *p*-value<0.01). As HBIs increase, the number of total and truck accidents increases at approaches. But, from a practical point of view, the value of R^2 is low indicating an insignificant degree of relationship.

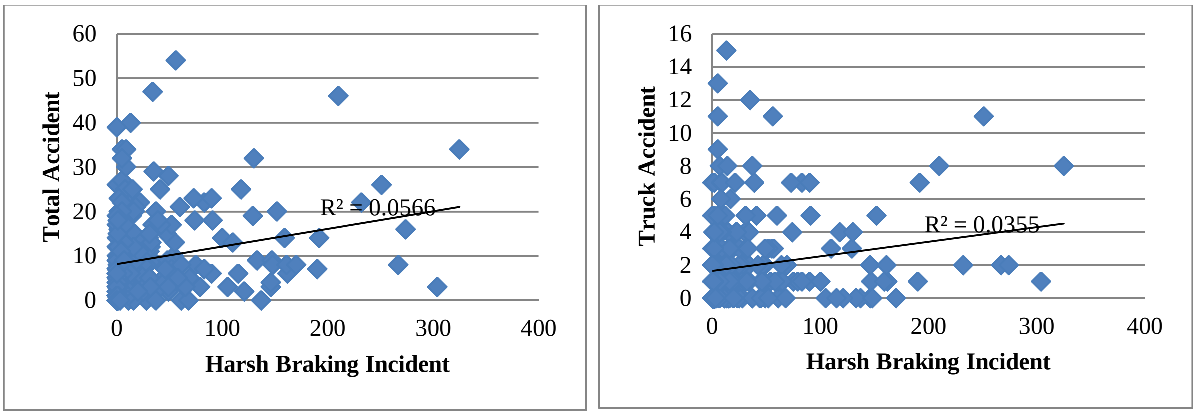


Figure 10-7 Relationship Between HBIs and Total Accidents (left) and Truck Accidents (right) at Approaches

As discussed earlier, when creating the accident prediction models, these are best represented by the NB distribution, and for this purpose random and fixed-parameters NB models were applied to the data. It was found that a random-parameters model best relates total accident numbers at approaches to the HBIs, traffic, and geometric parameters, while for truck accident numbers a random-parameters model was identified based only on HBIs and geometric variables, because adding traffic variables makes HBIs insignificant. Table 10-6 illustrates the results.

Table 10-6 Random-Parameter Results for Total and Truck Accidents at Approaches

Independent variable	Random parameters NB model for total accidents with geometric, AADT and HBI variables		Random parameters NB model for truck accidents with geometric, and HBI variables	
	Coefficient	*t*-stat	Coefficient	*t*-stat
Constant	-4.45	-4.905***	-1.43	-3.623***
HBI	0.002	1.977**	0.003	2.169**
ln(AADT)	0.59	5.869***		
Signal indicator (1 if signalised; 0 if un-signalised)	0.19	1.988**	0.272	1.858*
Lane number (1 if lane is two; 0 if three)	0.199	1.762*	0.0097	0.063
SD	*0.432*	*7.03****	*0.542*	*5.704****
Entry width	0.013	0.486	0.062	1.976**
SD	*0.007*	*1.67**		
Grade (1 if grade separated; 0 otherwise)	0.77	6.435***	1.23	5.239***
Log-likelihood at convergence	-876.7374		-501.6746	

* At 90% significance level   ** At 95% significance level   *** At 99% significance level

Table 10-6 indicates that total accident numbers are related to HBIs along with traffic and geometric variables, and Figure 10-8 (left) illustrates the relationship between the actual and predicted values of total accident numbers. The random parameters model identified for total accidents at approaches including HBI as an input variable were compared with the fixed-parameters model using χ^2, Eq. (3-12),[41] with two degrees of freedom, giving 86% confidence that the random-parameters model gives a better fit than the fixed-parameters model. For the model without HBI as an input variable the likelihood ratio test using χ^2 of 3.5334 with two degrees of freedom gives an 83% confidence that the random-parameters model provides a better fit; therefore harsh braking information delivers little advantage.

At approaches when total accidents are related to HBIs along with traffic and geometric variables, it was found that nearly the same regression coefficient was obtained when compared to the model identified for total accidents without HBIs (see Section 5.4, Table 5-4, and Figure 5-3). In addition, when HBIs are added to the model, entry width was found to have a significant positive effect on total accidents and was varied across observations but with low marginal value. However, this effect was found to be insignificant, statistically, with models without HBIs. In addition, the model including HBI as an input variable was compared to the model identified for total accidents in Table 5-4 without including HBI as input variable using AIC. It was found that the model with HBI as an input variable has lower AIC (1767.4748) compared to that without (1768.3064), indicating that having a model with HBIs alongside traffic and geometric variables gives a better fit than a model without HBIs.

Based on the results illustrated in Table 10-4, it was found that total accident numbers increase by an average of 1.5 (this corresponds to an increase in accidents of 16%)[42] , 0.59%, 1.45 (an increase in accident by 15%), and 5.85 (an increase in accident of 62%) with an increase of 100 in HBIs, with a 1% increase in AADT, and with signalised and grade-separated approaches, respectively. The influence of two-lane indicator and entry width on total accidents were found to vary across approaches, as indicated by the *t*-statistic of the SD in Table 10-6, in which 68% of two-lane approaches were associated with a higher number of total accidents, and 97% of the approaches with higher entry width recorded a higher number of total accidents. The average marginal effect indicates that total accident numbers increase by an average of 1.52 (an increase in accident by 16%) with the two-lane indicator, and a 1m

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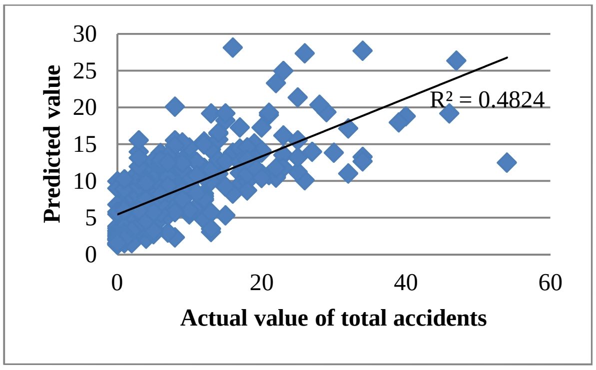
[41] The estimated log likelihood for the fixed parameters model was -878.7183.
[42] Average total accident per approaches is 9.4, so HBI corresponds to an increase in accidents by 16% ((1.5/9.4)*100). Note that at approaches average predicted total accidents are 9.1 which is close to 9.4 and so it will give similar results.

increase in entry width increased total accidents by an average of 0.093 (corresponding to an increase in accidents by 0.98%) over 11 years.



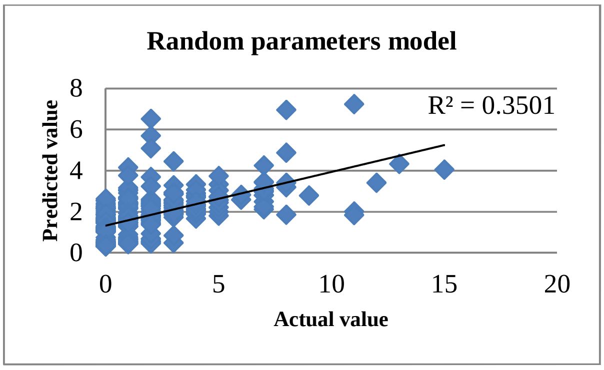


Figure 10-8 Predicted Value vs Actual Value of Total Accidents (left) and of Truck Accidents (right) at Approaches

When truck accident numbers were related to geometric and traffic variables along with HBIs it was found that HBIs were insignificant, while when traffic variables were removed a relationship was identified between truck accidents, HBIs and geometric variables, as illustrated in Table 10-6. Figure 10-8 (right), shows the predicted values against the actual values of truck accidents, showing that HBIs are not a good predictor of truck accidents. When truck accidents were normalised with truck traffic, no models were identified based on HBIs alone or HBIs combined with geometric variables.

Including HBIs in the models of truck accident numbers at approaches does not improve them, because they are insignificant when traffic is included. However, the relationship between HBIs and total accidents at all approaches was found to be better than the model without HBI as an input variable, which means it may be worth looking at the approaches with different geometric categories. For this purpose, the relationships between total and truck accidents and HBIs along with traffic and geometric characteristics at approaches based on different geometric characteristics were identified and illustrated in the following sections.

10.1.4 Relationship Between Total and Truck Accidents and Harsh Braking Incidents at Approaches Based on Different Geometric Parameters

The selected roundabouts have 284 approaches, which are either two lanes (172 approaches) or three lanes (112 approaches), located on A-class roads (174 approaches), B-class roads (16 approaches) or M-class roads (94 approaches), and signalised (142 approaches) or un-signalised (142 approaches). As such, it is clear that there are different categories of approaches, and in order to explore how HBIs are related to total and truck accident numbers, a NB model was applied to the accident data to explore their relation to traffic and geometric characteristics along with HBIs, based on the different approach categories. This analysis helps explore how HBIs in each approach category affect total and truck accident numbers along with other geometric and traffic parameters. The following subsections illustrate these relationships.

10.1.4.1 Relationship Between Total Accidents and Harsh Braking Incidents at Approaches Based on Different Geometric Parameters

The linear relationship between total accidents and HBIs was examined for each approach category and is presented in Appendix I.

Table 10-7 presents the relationship between total accident numbers and traffic and geometric characteristics and HBIs for different approach categories. The results of the NB models indicate that for un-signalised and two-lane approaches, HBIs are insignificant, statistically, when related to total accident numbers, and even remain insignificant when related to total accident numbers when traffic and geometric variables added. This reveals that there is no statistical relationship between total accident numbers and HBIs in un-signalised and two-lane approaches.

For approaches that are located **on A- and B-class roads**, it was found that total accident numbers are related to HBIs and geometric variables in a random-parameters model. The percentage of truck traffic will be insignificant when it is added to the harsh breaking HBIs and the significant geometric variables, while adding AADT to the model causes HBIs to be insignificant. Figure 10-9 shows the relationship between actual values and predicted values of total accident numbers on A- and B-class approaches based on harsh breaking HBIs and geometric parameters, and the predicted value is good based on only HBI and geometric variables.

Table 10-7 Relationship Between Total Accident numbers, HBIs, and Traffic and Geometric Variables

Independent Variable	Random parameters NB model for A- and B-class road (with geometric and HBI variables)		Fixed parameters NB model for M-class road (with only AADT and HBI variables)		Fixed parameters NB model for signalised approaches (with AADT, geometric, with HBI variables)		Model for un-signalised approaches (no model)		Model for two-lane approaches (no model)		Random parameters NB model for three-lane approaches (with truck traffic %, AADT, geometric, and HBI variables)	
	Coefficient	*t*-stat	Coefficient	*t*-stat	Coefficient	*t*-stat	Coefficient	*t*-stat	Coefficient	*t*-stat	coefficient	*t*-stat
Constant	0.433	1.20	-1.88	-1.15	-3.02	-2.5**					-3.91	-2.85**
HBI	0.003	2.1**	0.002	1.60*	0.002	2.46**					0.002	2.40**
Lane number indicator	0.12	0.81			0.26	2.11**			[redacted]			
SD	*0.80*	*10.91****										
Entry width	0.09	3.00***										
Percentage of Truck traffic											0.008	0.42
SD											*0.034*	*4.40****
AADT			0.45	2.58***	0.55	4.27***					0.59	4.04***
Signalised indicator	0.79	5.70***			[redacted]						0.40	2.30**
Road class indicator	[redacted]											

* At 90% significance level ** At 95% significance level *** At 99% significance level

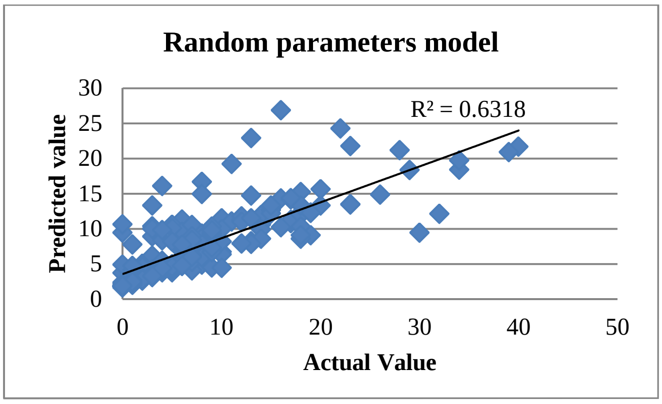


Figure 10-9 Predicted Value vs Actual Value of Total Accidents on A- and B-Class Approaches

However, because having a model with traffic and other variables is considered better, this model will not be useful for the improvement of these locations. In addition, a good model was identified for all approaches when analysed with all the geometric characteristics for this reason improvements can be done based on the resulting model illustrated in Table 10-6 for total accidents rather than a model based on only geometric and HBIs as input variables.

In A- and B-class approaches, in order to find the influence of total traffic on total accident numbers with HBIs and geometric variables, total accidents were normalised by total traffic and the data were re-analysed for the random and fixed-parameters NB models, but it was found that HBIs are not related to normalised total accidents.

For approaches that are located **on M-class roads**, a fixed-parameter NB model was identified. It was found that total accident numbers are related to HBIs and AADT, and it was found that when HBIs are added to the model, the geometric variables become insignificant. The following model is obtained for M-class roads:

$$Total\ accident_{(M\ road)} = 15\ \times 10^{-2} \times Q^{0.45} \times e^{0.002\ incident} \quad (10\text{-}4)$$

where Q is the approach AADT at the M-class road.

However, when the predicted values are related to the actual values, the model is not a strong model for predicting accidents on M-class roads (see Figure 10-10).

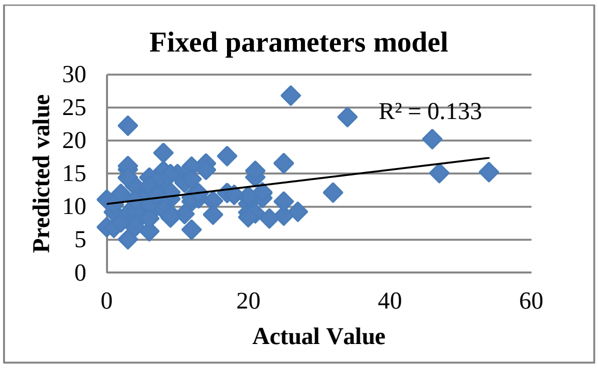


Figure 10-10 Predicted Value vs Actual Value of Total Accidents on M-Class Approaches

In order to get a better prediction, for M-class approaches, total accident numbers were normalised to total traffic and a random-parameter model was identified based on HBIs and geometric variables. The *LIMDEP* output results are shown in Table 10-8.

Table 10-8 *LIMDEP* Output for Random-Parameters Model Results for Approaches Located on M-Class Roads

Variable	Coefficient	Standard Error	b/St.Er.	P[|Z|>z]	Mean of X
Nonrandom parameters					
Constant	2.20867291	.21708865	10.174	.0000	
X1	.00216347	.00133176	1.625	.1043	39.3191489
X4	-.30731589	.18608662	-1.651	.0986	.72340426
Means for random parameters					
X2	.17232090	.17666781	.975	.3294	.56382979
Scale parameters for dists. of random parameters					
X2	.40317811	.11402554	3.536	.0004	
Dispersion parameter for NegBin distribution					
ScalParm	2.30233646	.48850014	4.713	.0000	

where: x1 is HBIs, x2 is the two-lane indicator, and x4 is the signalisation indicator.

According to this model it was found that the predicted value is a better fit to the actual value, as illustrated in Figure 10-11.

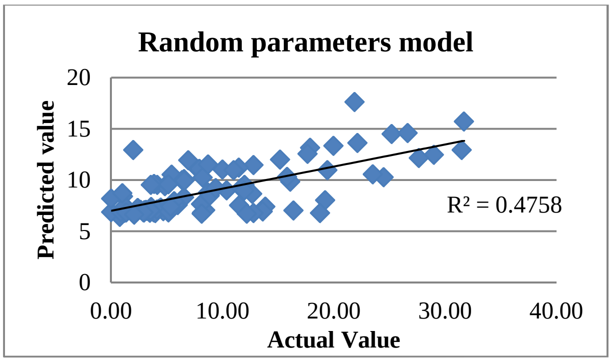


Figure 10-11 Predicted Value vs Actual Value of Normalised Total Accidents on M-Class Approaches

It was found that an increase in HBIs of 100 corresponds to an increase in normalised total accidents of 1.8 over 11 years. It was found that signalised M-class roads associated with lower normalised total accidents by an average of 2.68. The two-lane indicator results in a random parameter in which 66% of M-class approaches have increased total accidents by an average of 1.51. The influence of HBIs in M road approaches is different from A-class approaches, and this could be due to the number of HBIs being lower for A road approaches relative to M approaches (5144 HBIs in 190 A-class approaches (a rate of 27 per A-class approaches), relative to 3696 HBI in 94 M-class approaches (a rate of 39.3 per M-class approaches)).

Note that when the numbers of total accidents are related to AADT and percentage of truck traffic with respect to Road class at approaches (see Figure G-19, Appendix G), A- and B-class road with M-class road showed the same trend, for this reason road class was not included in the total accident models in the approaches presented in Chapter Five. But in order to explore if there is a better prediction model for normalised total accidents in M-class approaches without using HBIs as an independent variable, a random parameters model was developed (see Table 10-9). In addition, the estimated log likelihood for the normalised total accident models was -300.00, and the log likelihood for normalised total accident model without HBI as input variable is -302.21. This corresponds to a similar AIC (608.00) for the model including HBI and the model without HBI (608.42), but when the actual values were plotted against predicted values for this model it was found that the inclusion of HBIs in the model of normalised total accidents gave better prediction (Figure 10-11) relative to the model of normalised total accidents without HBIs (Figure 10-12). This indicates that having HBIs in the models is better than models without HBIs for normalised total accidents at M-class approaches. Note that there are 94 M-class approaches and Figure 10-12 shows that there are two different trends. One of the trends has a predicted value of 7.89 for all locations (41 approaches); it was found that 39 of these approaches are signalised and 2 of them are un-signalised, and all approaches with this predicted value have three lanes. The other 53 approaches have a trend with a predicted value that varies from 9.5 to 11.72, it was found that 29 of them are signalised, and the other 24 are un-signalised, and all of these approaches have two lanes. Two- and three-lane M-class approaches were not analysed separately because it was found in Section 10.1.3 that for all approaches together HBI have an significant effect on total accidents with traffic and geometric variables; therefore it is concluded that analysing all approaches together gives better, significant results.

Table 10-9 LIMDEP Output for Random-Parameters Model Results for Normalised Total Accidents without HBIs for Approaches Located on M-Class Roads

```
+--------+--------------+--------------+--------+--------+----------+
|Variable| Coefficient  | Standard Error |b/St.Er.|P[|Z|>z]| Mean of X|
+--------+--------------+--------------+--------+--------+----------+
--------+Nonrandom parameters
 Constant|     2.06630688       .12756009     16.199    .0000
--------+Means for random parameters
 X1      |      .25884548       .16746024      1.546    .1222      .56382979
--------+Scale parameters for dists. of random parameters
 X1      |      .21706011       .11567674      1.876    .0606
--------+Dispersion parameter for NegBin distribution
 ScalParm|     1.91592474       .40114087      4.776    .0000
```

where x1 is two-lane indicator at M-class approaches.

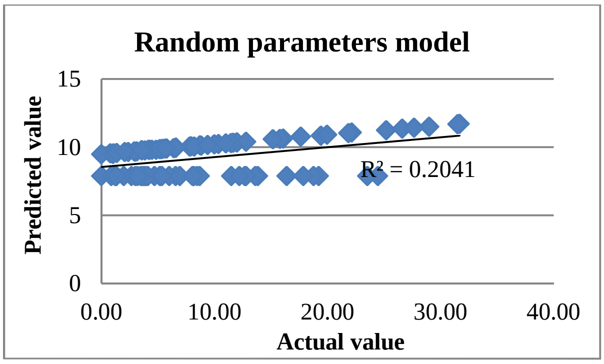


Figure 10-12 Predicted Value vs Actual Value of Normalised Total Accidents on M-Class Approaches without HBI

A fixed-parameter model was identified for **signalised approaches** based on HBIs, AADT, and a geometric variable (see Table 10-7). The resulting model is as follows:

$$Total\ accident_{(signalised\ approaches)} = 4.8 \times 10^{-3} \times Q^{0.55} \times e^{0.002\ incident + 0.26\ two\ lane} \qquad (10\text{-}5)$$

However, because the model is fixed, the predicted value is related to the actual value in a lower goodness of fit (see Figure 10-13). All the variables were tested as random, but it was found that they have fixed effects across the observations on total accident numbers at signalised approaches. When the data was normalised with total traffic and re-analysed, it was found that HBIs are not related to normalise total accidents at signalised approaches.

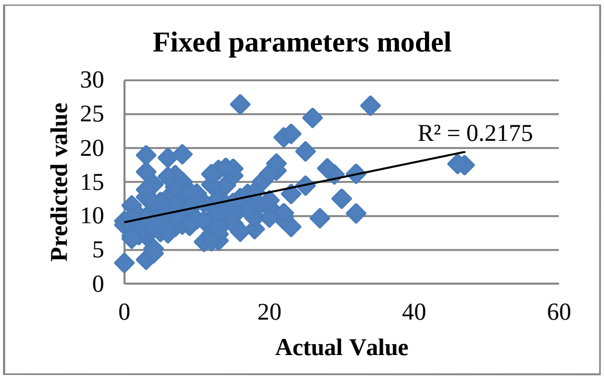


Figure 10-13 Predicted Value vs Actual Value of Total Accidents at Signalised Approaches

A random-parameter model was identified for **three-lane approaches** (see Table 10-7). It was found that total accidents at three-lane approaches are related to HBIs, AADT, truck percentage, and the road class indicator. Figure 10-14 demonstrates the relationship between actual values and predicted values for total accidents at three-lane approaches.

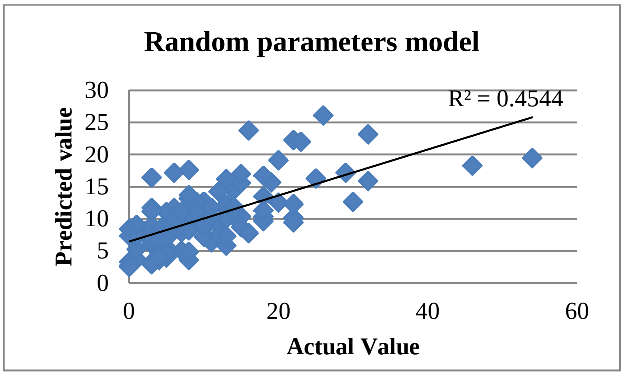


Figure 10-14 Predicted Value vs Actual Value of Total Accidents at Three-Lane Approaches

According to the marginal effects, increasing HBIs by 100 associated with an increase in total accidents by an average of 2 (average total accidents per three-lane approach is 6.89, so this marginal effect corresponds to a 29% increase in total accidents), a 1% increase in AADT leads to a 0.59% increase in total accident numbers, and in addition signalised three-lane approaches are associated to a higher number of total accidents by an average of 3.68 (corresponds to 53% increase) over the 11-year period. Truck traffic resulted in a random parameter: 60% of three-lane approaches with higher truck traffic percentages have higher numbers of total accidents and 40% have lower numbers, and a 1% increase in truck traffic increases total accident numbers by an average of 0.071% over 11 years. As with the other type of approaches, in order to get a better prediction, total accidents at three-lane approaches were normalised to total traffic, but it was found that HBIs are not related to normalise total accidents.

10.1.4.2 Relationship Between Truck Accidents and Harsh Braking Incidents at Approaches Based on Different Geometric Characteristics

The linear relationships between total accidents and HBIs were examined for each approach category, and are presented in Appendix I.

Table 10-10 presents the relationships between truck accidents and traffic and geometric characteristics, and HBIs, for A-class and M-class roads, for signalised and un-signalised approaches, and for two and three-lane approaches. It was found that on A- and B-class roads, at un-signalised and two-lane approaches, HBIs are insignificant when traffic and geometric variables are added and related to truck accidents in NB regression models, and even remain insignificant when they are related to truck accidents alone. This reveals that there is no statistical relationship between truck accidents and HBIs in A-class, un-signalised and two-lane approaches.

For A- and B-class approaches, a fixed-parameters NB model was identified when truck accidents were normalised by truck traffic, and the model is as follows:

$$\left(\frac{Truck\ accident}{Truck\ traffic}\right)_{A\ road} = 7.31 \times 10^{-4} \times e^{-0.003\ incident + 0.34\ two\ lane + 0.29\ signal} \qquad (10\text{-}6)$$

Figure 10-15 illustrates the relationship between actual and predicted values for normalised truck accidents at A-class approaches: it is clear that because the model is a fixed model the predicted value does not fit the data. When the random-parameters model was applied to the data, all significant parameters were found to have fixed effects.

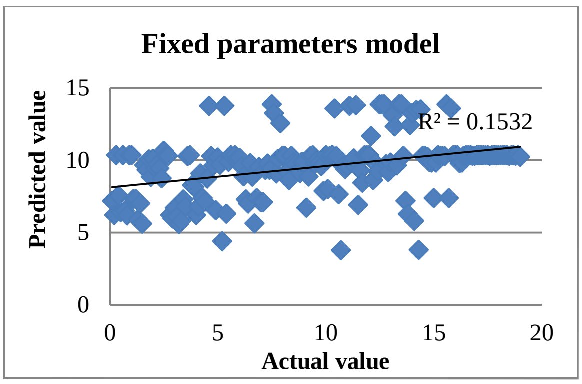


Figure 10-15 Predicted Value vs Actual Value of Normalised Truck Accidents at A-Class Approaches

Table 10-10 Relationship Between Truck Accidents, HBIs, and Traffic and Geometric Variables

Independent variable	Model for A- and B- class road (no model)		Random parameters NB model for M-class road (with traffic, geometric, and HBI variables)		Random parameters NB model for signalised approaches (with HBI and geometric variables)		Model for un-signalised approaches (no model)		Model for two-lane approaches (no model)		Random parameters NB model for three-lane approaches (with geometric and HBI variables)	
	Coefficient	*t*-stat	Coefficient	*t*-stat	Coefficient	*t*-stat	coefficient	*t*-stat	Coefficient	*t*-stat	Coefficient	*t*-stat
Constant			-5.40	-2.70**	0.78	6.69***					0.61	1.293
HBI			0.002	1.78*	0.003	2.06**					0.003	1.83*
Lane number indicator			0.09	0.46	0.013	0.07			[redacted]			
SD			*0.325*	*2.77****	*0.284*	*2.07***						
Entry width											0.07	1.83*
SD											*0.022*	*2.69***
Truck traffic			0.06	1.98**								
SD			*0.06*	*4.86****								
Total traffic			0.58	2.75***								
Signalised indicator			0.06	0.27	[redacted]						0.49	2.69***
SD			*0.41*	*3.89****							*0.184*	*1.72**
Road class indicator	[redacted]											

*At 90% significance level ** At 95% significance level *** At 99% significance level

When truck accidents were normalised to truck traffic there was still no relationship between normalised truck accidents and HBIs for two-lane and un-signalised approaches.

As for total accidents, when truck accidents are related to AADT and percentage of truck traffic linearly with respect to Road class at approaches (see Figure G-20, Appendix G), A- and B-class roads and M-class roads showed the same trend. For this reason road class was not included in the truck accident models at approaches presented in Chapter Five. But in order to explore if there is a better prediction model for normalised truck accidents in A-class approaches without HBI, a random and a fixed parameters model were applied to the normalised truck accidents at A- and B-class approaches without adding HBIs, and it was found that all the geometric variables have insignificant effect on truck accident occurrences as shown in Table 10-11. This indicates that the model identified for normalised truck accidents at A- and B-class approaches based on HBIs is considered better, because when HBIs are added to the model two-lane and signalised indicators were found to be significant, statistically, in addition to HBI.

Table 10-11 *LIMDEP* Output for Normalised Truck Accidents without HBIs for Approaches Located on A- and B-Class Approaches

Variable	Coefficient	Standard Error	b/St.Er.	P[|Z|>z]	Mean of X
Nonrandom parameters					
Constant	1.40306428	1.35637015	1.034	.3009	
X1	.53184192	.63943026	.832	.4056	.62631579
X2	.14835725	.11131339	1.333	.1826	9.62310526
X3	.37451456	.55450723	.675	.4994	.38947368
Dispersion parameter for NegBin distribution					
ScalParm	.20588057	.02200772	9.355	.0000	

Where x1 is two-lane number indicator, x2 is entry width, and x3 is signalised indicator.

For M-class roads, a random-parameters NB model was identified for truck accidents (see Table 10-10), and it was found that truck accidents are related to HBIs along with traffic and geometric parameters. Figure 10-16 illustrates the predicted value vs the actual value of truck accidents at M-class approaches, showing a good fit to the data and therefore a good model.

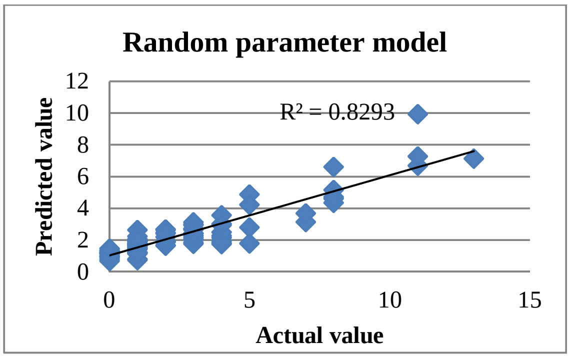


Figure 10-16 Predicted Value vs Actual Value of Truck Accidents at M-Class Approaches

The marginal effect indicates that the number of truck accidents at M-class approaches increase by an average of 0.4 when HBIs increase by 100, and 1% of AADT increases truck accidents by an average of 0.58 (see Table 10-10). The two-lane indicator, the truck traffic percentage, and the signalised indicator resulted in random parameters, in which 61%, 83%, and 56%, respectively, of M-class approaches had higher numbers of truck accidents. Two-lane M-class approaches increase accidents by an average of 0.17, a 1% increase in truck traffic increases truck accident numbers by an average of 0.11%, and signalised M-class approaches increase truck accident numbers by an average of 0.11 over 11 years.

In order to explore if there is a better prediction without having HBIs in the model as an independent variable for M-class approaches a random parameters model is estimated based on traffic and geometric variables (see Table 10-12 for the *LIMDEP* output result). Models with HBIs resulted in a lower log likelihood (-190.8526) but higher AIC (395.7052) because of higher numbers of estimated parameters relative to the model without HBI, as the input variable has a higher log likelihood (-192.0066) but lower AIC (394.0132). However, when the actual value of truck accidents was plotted against the predicted value, it was found that the inclusion of HBIs in the model of truck accidents gives a better prediction (Figure 10-16) relative to the model of truck accidents without HBIs (see Figure 10-17) at M-class approaches.

Table 10-12 LIMDEP Output for Truck Accidents without HBIs for Approaches Located on M-Class Approaches

Variable	Coefficient	Standard Error	b/St.Er.	P[|Z|>z]	Mean of X
Nonrandom parameters					
Constant	-5.87209256	2.36478632	-2.483	.0130	
X3	.06383253	.03252305	1.963	.0497	6.78938298
X4	.65443690	.25029949	2.615	.0089	9.45233830
Means for random parameters					
X1	.02601822	.21686816	.120	.9045	.56382979
X5	.01553930	.23041783	.067	.9462	.72340426
Scale parameters for dists. of random parameters					
X1	.23847406	.13376701	1.783	.0746	
X5	.46525647	.12795567	3.636	.0003	
Dispersion parameter for NegBin distribution					
ScalParm	2.37777989	.84935686	2.800	.0051	

Where x1 is two-lane indicator, x3 is percentage of truck traffic, x4 is ln(AADT), and x5 is signalised indicator.

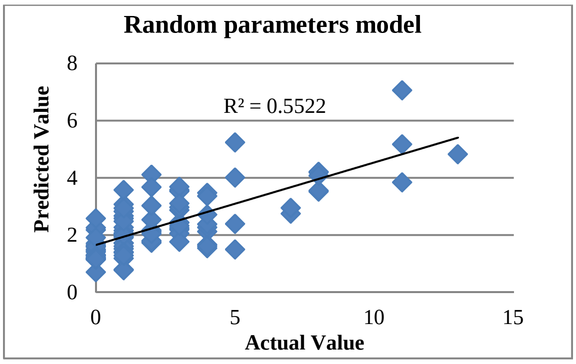


Figure 10-17 Predicted Value vs Actual Value of Truck Accidents without HBI at M-Class Approaches

For signalised and for three-lane approaches, HBIs were only related to truck accidents when geometric parameters were added, while when truck traffic percentage and AADT were added to the model, HBIs become insignificant. Truck accidents were normalised by truck traffic, but it was found that there is no relationship between normalised truck accidents and HBIs for signalised and three-lane approaches. For this reason, only a model with HBIs and geometric parameters was presented for signalised and three-lane approaches (see Table 10-10). For signalised approaches the resulting predicted values based on HBIs and the two-lane indicators do not fit the actual values, as illustrated in Figure 10-18. For three-lane approaches the resulting predicted value of truck accidents based on HBIs and the two geometric variables presents a better prediction than for signalised approaches (see Figure 10-19).

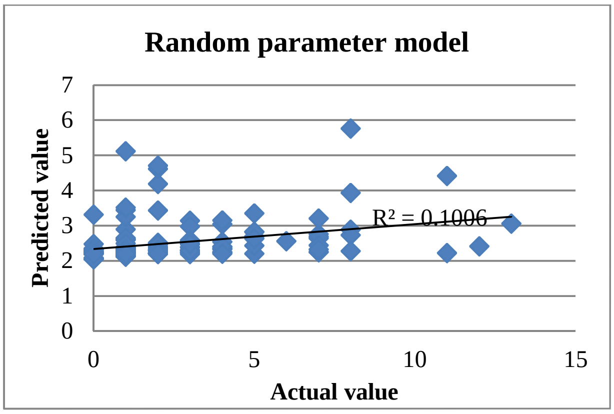


Figure 10-18 Predicted Value vs Actual Value of Truck Accidents for Signalised Approaches

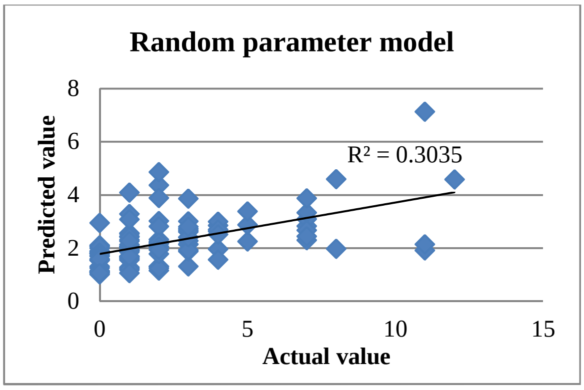


Figure 10-19 Predicted Value vs Actual Value of Truck Accidents at Three-Lane Approaches

10.1.5 Relationship Between Total and Truck Accidents and Harsh Braking Incidents for Grade-Separated and At-Grade Roundabouts

As discussed in Chapter Five, because the correlation results indicated that the grade indicator was highly correlated with ICD, so the type of grade was removed from the models, and at-grade locations and grade-separated locations were analysed separately from the whole 70 selected roundabouts. It was found that there was a difference between the factors influencing accidents in the grade-separated and at-grade locations, probably due to the difference in geometric characteristics of the two types of grade. For this reason, total and truck accidents were related to HBIs along with geometric and traffic variables, as is illustrated in the following subsections.

10.1.5.1 Relationship Between Total and Truck Accidents and Harsh Braking Incidents for Grade-Separated Roundabouts

Figure 10-20 illustrates the relationship between total and truck accidents with HBIs for the selected grade-separated roundabouts. The value of R^2 between total accidents and HBIs is higher than the value of R^2 found between truck accidents and HBIs. The probable reason is that the number of truck accidents is lower than the number of total accidents, and high numbers of HBIs were recorded in the selected grade-separated locations. However, the ANOVA results between accidents and HBIs reveal that both R^2 values are significant. A linear test between the two indicates that there is, statistically, a significant linear relationship between total accidents and HBIs (F (1, 49) = 12.753, p-value<0.01). In addition, a significant statistical linear relationship was identified between truck accidents and HBIs (F (1, 49) = 7.965, p-value<0.01). This indicates that for grade-separated roundabouts, as the number of HBIs increases, total and truck accidents increase. However, from practical point of view with this is a small R^2 and there is not a linear relationship between accidents and HBIs.

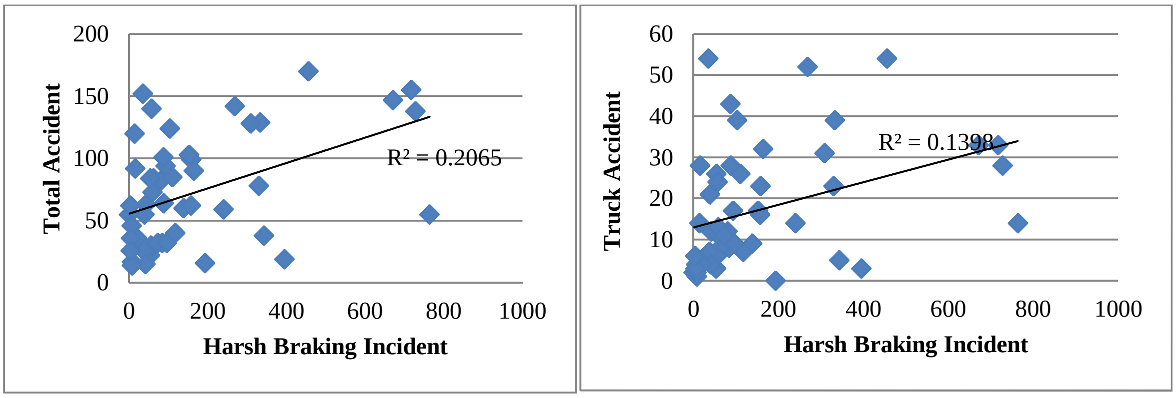


Figure 10-20 Relationship Between Total Accidents and HBIs (left) and Between Truck Accidents and HBIs (right) for Grade-Separated Roundabouts

In order to identify the influence of HBIs along with traffic and geometric characteristics on total and truck accident numbers at the selected grade-separated locations, a random and a fixed-parameters NB regression were applied to the number of accidents. Table 10-13 illustrates the model's estimated results for total and truck accidents. There is a relationship between total accidents and geometric variables, as illustrated in Table 10-13, but when traffic variables were added to the estimated model, HBIs became insignificant.

Table 10-13 Total and Truck Accident Correlation with HBIs and Geometric Parameters for Grade-Separated Roundabouts

Independent variable	Random parameters NB model for total accident with geometric, and HBI variables		Fixed parameters NB model for truck accident with HBI variable	
	Coefficient	*t*-stat	Coefficient	*t*-stat
Constant	3.14	11.359***	2.55	16.466***
HBI	0.0008	5.030***	0.002	1.904*
ICD	0.007	6.649***		
Un-signal indicator	-0.77	-8.147***		
Four-arm indicator	0.096	1.277		
SD	*0.46*	*11.039****		
Entry width	-0.031	-1.589		
SD	*0.0192*	*6.662****		
Signal indicator	0.02	0.284		
SD	*0.377*	*7.444****		
Log-likelihood at convergence	-243.5071		-193.8079	

*At 90% significance level **At 95% significance level ***At 99% significance level

When total accidents were normalised with total traffic and the data re-analysed, there was no statistically significant relationship between normalised total accidents and HBIs, as indicated by the *t*-statistic (see Table 10-14).

Table 10-14 *LIMDEP* Output for Normalised Total Accidents and HBIs

```
+--------+--------------+----------------+--------+--------+----------++----------++----------++----------++----------+
|Variable| Coefficient  | Standard Error |b/St.Er.|P[|Z|>z]| Mean of X|
+--------+--------------+----------------+--------+--------+----------+
--------+Nonrandom parameters
 Constant|    2.64067867        .12827497     20.586   .0000
 X1      |   -.596087D-05       .00050616     -.012    .9906    159.372549
--------+Dispersion parameter for NegBin distribution
 ScalParm|    2.44318076        .55028263      4.440   .0000
```

where x1 is a HBI.

Figure 10-21 (left) compares the actual value of total accidents to the predicted value: it is clear that the estimated HBI and geometric variables are the best fit for the data based on the identified R^2, and on slope of the relationship (≈ 1).

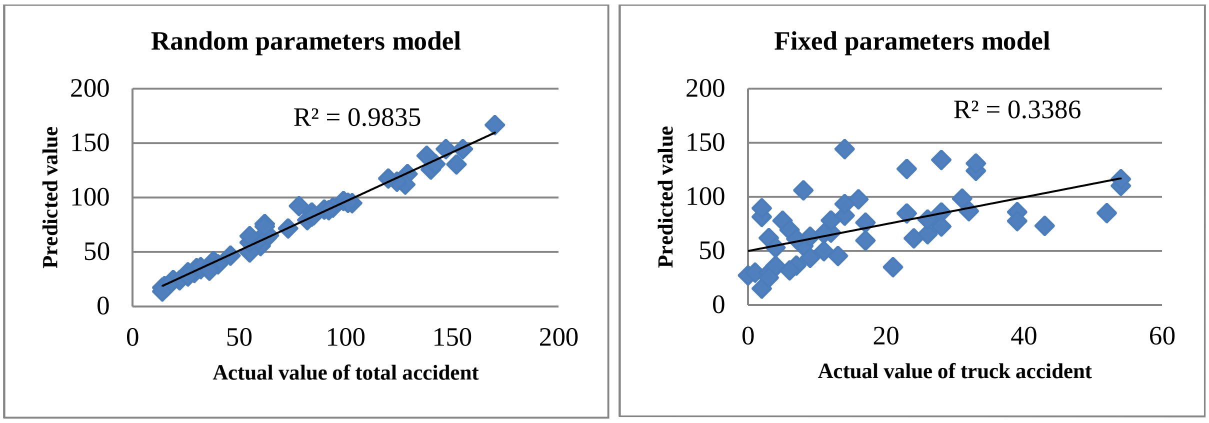


Figure 10-21 Predicted Value vs Actual Value of Total Accidents (left) and of Truck Accidents (right) for Grade-Separated Roundabouts

The resultant model, including HBI as an input variable, was compared to the model identified for total accidents reported in Table 5-6, without including HBI as an input variable using AIC. It was found that the model with HBI as an input variable has a higher AIC (501.0142) compared to the model without HBI as an input variable (484.5042). This means that for total accidents at grade-separated roundabouts, having a model with traffic and geometric variables is better than a model with HBI and geometric variables. This indicates that traffic variables have a larger impact on total accidents at grade-separated roundabouts than HBIs, and similar results were identified for all 70 whole roundabouts.

A significant fixed NB model was identified when truck accidents were related to HBIs in grade-separated roundabouts. The resulting model is:

$$Truck\ accident_{(grade-separated)} = 12.8 \times e^{0.002\ incident} \tag{10-7}$$

This model has a high constant value, which indicates that when HBIs are zero at a roundabout, there are still a high number of truck accidents. Figure 10-21 (right), illustrates the correlation between the actual and predicted values of truck accidents based on the model (Eq. 10-7); as it is a fixed model and high constant value and only one variable is included in the model, it results in a biased estimate. When traffic and geometric parameters are added to the model, HBIs become insignificant, and HBI remain insignificant when truck accidents are normalised with truck traffic. Similar to total accident models, the model identified for truck accidents without HBI as an input variable (see Table 5-12) is considered better than the model including HBI as an input variable (AIC of 391.6158 relative to AIC of 350.0448).

10.1.5.2 Relationship Between Total and Truck Accidents and Harsh Braking Incidents for At-Grade Roundabouts

Figure 10-22 shows the relationship between total and truck accidents and HBIs for at-grade locations. According to R^2 it is clear that they are not related, however, the ANOVA results indicate that there is no linear relationship between total accidents and HBIs (F (1, 17) = 0.462, p-value=0.506), or between truck accidents and HBIs (F (1, 17) = 0.108, p-value=0.747). The probable reason for these results is that the majority of the selected at-grade roundabouts have high numbers of HBIs with low numbers of total and truck accidents. Note that the three outliers in Figure 9-20 (right) show high numbers of total accidents, these locations are the A1237/A64, which is a signalised three-arm roundabout, the A46/ B6326, which is a partially signalised five-arm roundabout with a high percentage of truck traffic (9%), and the A46/A46/B6166, which is an un-signalised five-arm roundabout with a high percentage of truck traffic (10%). Compared with other at-grade roundabouts, the high percentage of truck traffic appears to be associated with higher numbers of total accidents. The outliers in Figure 10-22 (left) are at the same locations that were found as outliers in Figure 10-22 (right) which are the A46/ B6326 and A46/A46/B6166 junctions.

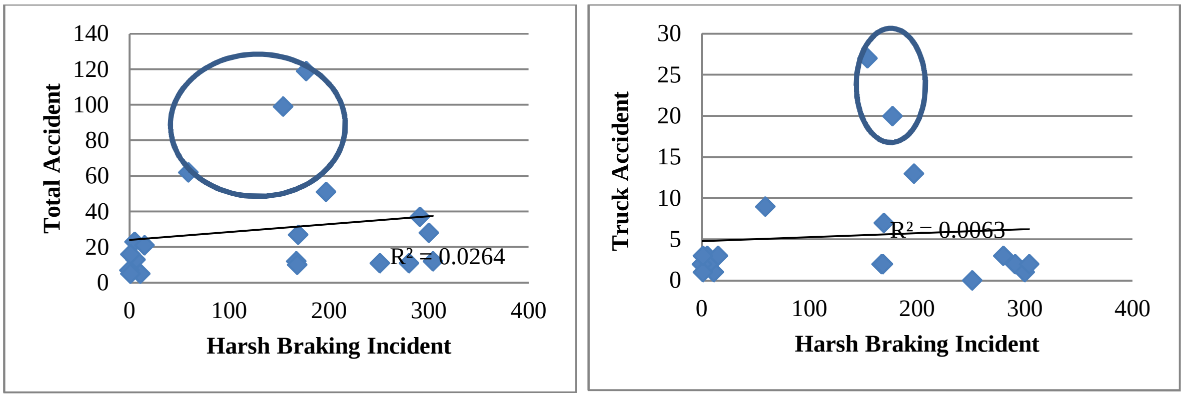


Figure 10-22 Relationship Between Total Accidents and HBIs (left) and Between Truck Accidents and HBIs (right) for At-Grade Roundabouts

When a NB distribution was applied to total and truck accidents in at-grade locations, it was found that total and truck accident numbers were related to HBIs along with geometric factors and AADT. Table 10-15 presents the estimated model results for total and truck accidents. In contrast to grade-separated locations, the influence of HBIs on the numbers of total and truck accidents in at-grade locations is negative; an increase in 100 HBIs over 2 years corresponds to a decrease in total and truck accidents by an average of 7.7 and 2.2, respectively, over 11 years.

Table 10-15 Total and Truck Accident Correlation with HBIs and Geometric Parameters for At-Grade Roundabouts

Independent variable	Random parameters NB Model for total accident with geometric, flow and HBI variables		Fixed parameters NB model for truck accident with geometric, and HBI variables	
	Coefficient	*t*-stat	Coefficient	*t*-stat
Constant	-13.91	-4.926***	-16.59	-2.905***
HBI	-0.004	-2.278**	-0.005	-2.758***
Un-signal indicator	-0.745	-2.171**	-0.747	-1.767*
AADT	1.99	7.325***	1.89	3.509***
Circulatory width	-0.23	-2.23**	-	-
Signal indicator	0.082	0.210	-	-
SD	*0.947*	*2.859****	-	-
Log-likelihood	-68.64		-46.86	

*At 90% significance level **At 95% significance level ***At 99% significance level

Based on the random-parameters model identified for at-grade locations, a good fit was identified when actual values were compared to the predicted values of total accidents, as shown in Figure 10-23 (left). However, the model identified for total accidents at at-grade locations illustrated in Section 5.6 is a random parameters model based on an un-signalised indicator, AADT and percentage of truck traffic (it does not use HBIs as input parameter). A better prediction (see Table 5-8, and Figure 5-5) relative to the model identified for total accidents at at-grade locations includes HBIs as an input (see Figure 10-23 (left)). However, adding HBI to the model of total accidents at at-grade locations resulted in a better log likelihood at convergence and a lower AIC (149.28) relative to the model of total accidents at at-grade roundabouts without HBI as an input variable, having AIC of 155.86. This indicates that using HBI data as input variable improves the overall fit of the model.

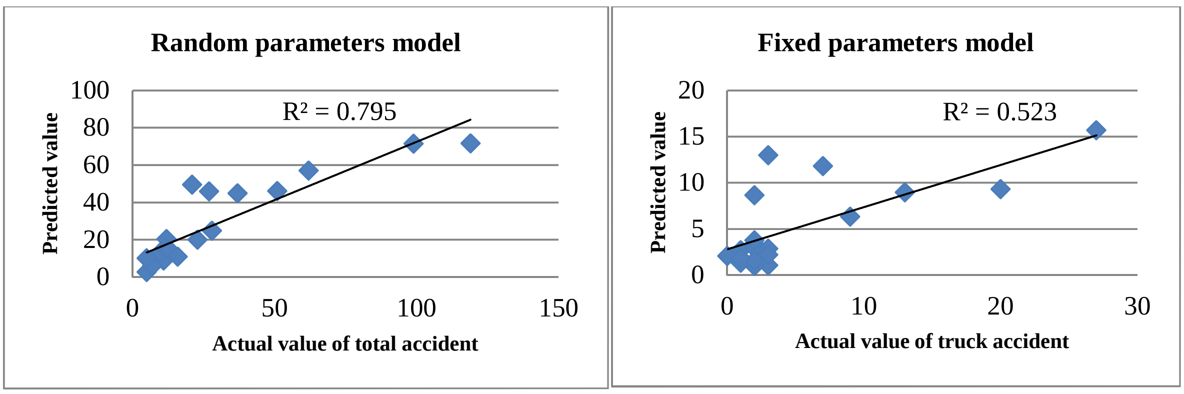


Figure 10-23 Predicted Value vs Actual Value of Total Accidents (left) and of Truck Accidents (right) for At-Grade Roundabouts

When truck accidents were related to HBIs and geometric and traffic variables, it was found that all variables have a fixed effect across at-grade roundabouts (see Table 10-15), and the following model was obtained:

$$Truck\ accident_{at-grade} = 6.24 \times\ 10^{-8} \times Q^{1.89}\ \times e^{-0.005\ incident-0.75\ un\_signal} \qquad (10\text{-}8)$$

Figure 10-23 (right) illustrates the relationship between actual and predicted values of truck accidents, and its fit is good compared with the other identified fixed models that include harsh braking as an input variable. For example, compare this model to the model identified for truck accidents at at-grade locations illustrated in Section 5.9 (see Table 5-14, and Figure 5-11) which does not include harsh braking as input variable. A similar fixed parameters model based on AADT and un-signalised indicator was obtained there, but a better prediction is identified when HBIs are added to the model. Adding HBI to the model of truck accidents at at-grade locations resulted in a better log likelihood at convergence and a lower AIC (96.9) relative to the model of total accidents at at-grade roundabouts without HBI as an input variable, having AIC of 99.72.

These results indicate that a model including HBI as an input variable along with traffic and geometric variables for both total and truck accident at at-grade roundabouts yields better overall fit than a model with only traffic and geometric variables, but the influence of HBIs at at-grade roundabouts on both types of accidents was found to be negative, which indicates that as HBIs increase, accidents decrease. The probable reason for this result is that the rate of HBI in at-grade roundabouts is high (134.5 relative to 159.4 for grade-separated), while the rate of total accidents at at-grade roundabouts is low (29.9 relative to 71.9 for grade-separated), particularly for truck accidents (5.4 relative to 17.3 for grade-separated). The higher number of HBIs is associated with the lower number of accidents at at-grade roundabouts. Because only 19 at-grade roundabouts were included in this study, more investigation including more observations is necessary.

10.2 Discussion

Total Accidents

- Total accidents were compared to HBIs along with traffic and geometric variables in all approaches (M-class, three-lane and signalised). For the majority of approach categories, total accidents were found to be related to HBIs along with traffic and geometric variables, so at all approaches, HBI should be considered as an important variable along with traffic and geometric variables for assessing future accident risk.

- HBI data was found to be a significant input variable to the total accident prediction models, alongside traffic and geometric variables for all types of approaches considered together. Although HBI and geometric data were significant input parameters for whole roundabouts, grade-separated roundabouts, and for A- and B-class approaches considered alone, once traffic variables were included as an additional input variable HBI data became an insignificant input.

The reason why HBI data is a significant predictor in only some circumstances, but not in others is not clear, but probably is due to the following:

- When approaches are analysed the traffic is per approach, whereas for the whole roundabouts overall all traffic data is the input.
- When approaches are analysed entry width is per approach, whereas for the whole roundabouts entry width is the average of all approaches.
- Inscribed circle diameter was considered for whole roundabouts as an input variable whereas at approaches this effect is not considered.
- Signalised and un-signalised indicators were compared to a partially signalised indicator when they were included as input variables in the model of whole roundabouts, while individual approaches were either signalised or not, limiting the possibility for direct comparison between approaches and the whole roundabout data.

- Within the circulatory lanes, HBIs and percentage of truck traffic are associated with total accidents, but when geometric variables are added to the model, HBIs become an insignificant parameter. This indicates that geometric variables are more important than HBIs within circulatory lanes. However, only 13% of HBIs occurred, although 32% of total accidents were recorded, within circulatory lanes, which is a probable reason for the lower significance of HBIs relative to geometric variables. The probable reason for lower HBIs within circulatory lanes is that circulatory lanes have curved sections, in which harsh cornering may occur rather than harsh braking. Having harsh cornering and harsh braking data would probably change the results. Therefore, further investigations are required, including records of harsh cornering events.
- At at-grade roundabouts it was found that, as HBIs increase, total accidents decrease. The probable reason is the higher rate of HBIs is recorded in at-grade roundabouts relative to

total accidents (135 relative to 29). However, this effect will be clearer by considering a higher number of at-grade roundabouts. Therefore, more investigation is recommended, including more observation of at-grade roundabouts.

Truck Accidents

- As for total accidents, for M-class approaches truck accidents were related positively to HBIs along with traffic and geometric variables. The consideration of HBIs as part of total accidents in these approaches is, therefore, important for making these approaches safer.
- For whole and at grade-separated roundabouts, truck accidents were only related to HBIs. When traffic and geometric variables were added to the model, HBIs became an insignificant parameter. As discussed earlier, this is an indicator that traffic and geometric variables are more associated with truck accidents than HBIs.
- Within the circulatory lanes, HBIs and AADT were associated with truck accidents, but when geometric variables were added to the model HBIs became insignificant. This indicates that geometric variables are more important than HBIs within circulatory lanes. However only 13% of HBIs and yet 36% of truck accidents occurred in such lanes, which is a probable reason for the insignificance of HBIs relative to geometric variables, as before, is discussed earlier, within circulatory sections harsh cornering in addition to harsh braking may occur, therefore further investigations are required, including records of harsh cornering events.
- At all approaches at signalised and three-lane approaches when analysed separately from all approaches, HBIs were related to truck accidents only with geometric variables. When traffic variables were added to the model the effect of HBIs, statistically, will be insignificant. Traffic variables (AADT and percentage of truck traffic) have a greater impact on accident occurrences, as found by previous studies discussed in this thesis, and in this study as well. The percentage of HBIs at approaches in a two-year period is much higher than the truck accident percentage in an eleven-year period (87% relative to 64%), and the rate of HBIs is 31 per approach, while the rate of truck accidents is only 2 per approach. Longer trends of HBIs at approaches might reveal their effect on truck accidents along with traffic and geometric variables. In addition, the speed of vehicles and signalisation will probably have different influences along with HBIs, on truck accidents. As found in Section 6.3, these HBIs occurred at different speeds and at different distances from approaches, and differ if the

approach is signalised or not. All these characteristics, along with traffic and geometric variables, require further investigation.

- At at-grade roundabouts and at A- and B-class approaches when analysed separately from all approaches, the influence of HBI was found to be negative on truck accidents (i.e. as HBI increases, truck accidents decrease). There are 190 A- and B-class approaches, and 19 at-grade roundabouts. The rate of truck accidents is 2 per at-grade roundabout and 5 per A- and B-class approach, respectively, while the rate of HBIs is much higher for at-grade roundabouts (135) and A- and B-class approaches (27), indicating the negative effect of HBIs. However, regarding the geometric variables, this study has identified that similar geometric factors influenced truck accidents and HBIs, so it is suggested that A- and B-class approaches, because of the high rate of HBIs relative to low rate of truck accidents, might exhibit future accident risk. As in the case of total accidents, because the number of at-grade roundabouts included in this study is not high, further investigation is required with a higher number of observations for at-grade roundabouts.

Total and Truck Accidents

- For two-lane and un-signalised approaches when analysed separately, HBIs were not related to total and truck accidents. However, for total accidents when all approaches were analysed together, HBIs were found to have a significant positive relationship to total accidents, along with traffic and geometric variables. This indicates that analysing all approaches for total accidents together gives more significant and reliable results than separating them, whereas the analysis of truck accidents on A- and B-class approaches should be considered separately from M-class approaches, as the effect of HBI was negative in A- and B-class roads which is in contrast to the positive effect of HBIs on M-class roads.

General Conclusion

When low numbers of truck accidents were available, different models that include HBIs as an input variable were estimated from those models of total accidents at:

- Whole roundabouts
- Grade-separated roundabouts
- All approaches
- Signalised, three-lane, and at A- and B-class approaches.

HBIs were found to be more associated with total accident occurrence, rather than with truck accidents alone, with only geometric variables or with both geometric and traffic variables also being important. The fact that these are only a small number of truck accidents means that these models are less reliable. In addition, it seems that truck accidents are more related to geometric and traffic variables than to HBIs. A further point to consider is that, when there is a truck on the road, it probably influences the behaviour of the other vehicles' drivers, more than another car would, and this may result in such differences between the relationships of accident types to HBIs.

It can be concluded that, for the locations where the influence of HBIs becomes statistically insignificant by adding traffic variables, traffic variables are more important than HBIs. However, longer trends of HBIs at approaches might reveal their effect on truck accidents along with traffic and geometric variables.

10.3 Summary and Conclusion

The main aim of this thesis is to explore if it is possible to improve identification of locations where the risk of accidents is high, based on truck data namely HBIs. For this purpose, HBIs were used, along with traffic and geometric variables, as an independent variable for predicting total and truck accidents. For whole roundabouts, within circulatory lanes, at approaches, and at grade-separated roundabouts, significant linear relationships were identified between total and truck accidents and HBIs. The ANOVA results show that as HBIs increase, total and truck accidents increase in the mentioned roundabout categories, but practically, because of low R^2 are considered insignificant. For at-grade roundabouts, however, no significant linear relationship was identified between total and truck accidents and HBIs.

Random and fixed-parameters NB models were used to identify the relationship between total and truck accident numbers with HBIs along with traffic and geometric variables for different roundabout category. Table 10-17 presents the key summary of the chapter results.

Table 10-16 Summary of the Models Identified with Respect to Roundabout Geometric Category

Roundabout category	Total Accident numbers	Normalised total accidents (total accident/AADT)	Notes	Truck Accident numbers	Normalised truck accident (truck accident/ truck %)	Notes
Whole roundabouts	A random parameters model including HBI and geometric variables	No model	A good prediction But adding AADT, HBI will be insignificant, The model without HBI as input variables gives a better overall fit	No model	No model	
Within circulatory lanes	A fixed parameters model with HBI and truck%	No model	The prediction is not good Adding any geometric variables HBI become insignificant The model without HBI as input variables gives a better overall fit	A fixed parameter model including AADT and HBI	No model	The prediction is bad Adding any geometric variables HBI became insignificant
At all approaches	A random parameter model including AADT, HBI, and geometric variables[43]		Better overall fit compared to the model without HBI s. When HBI added to the model entry width was found to have positive effect and this is in line with previous studies (Retting ,2006; Kim et al., 2013; Maycock and Hall, 1984)	A random parameters model including geometric variables and harsh braking HBI	No model	The prediction is not good Adding traffic variables HBI become insignificant

[43] Underlined models means the significant models having HBI as input variable

Table 10-17 continued

M-class approaches	A fixed parameter model including flow and HBI s	When accident normalised a better prediction random parameter model were identified including HBI and geometric variables	The prediction of the normalised model is improved when HBI is added relative to the model without HBI s	A Random parameters model including HBI , AADT, and geometric variables	No model	The prediction of the models is improved when HBI is added relative to the model without HBI s
A- and B-class approaches	A random parameters model including HBI and geometric variables	No model	When AADT added to the model HBI become insignificant	No model	A fixed parameter model identified and the effect of HBI was negative	The prediction of the models is improved when HBI is added relative to the model without HBI s But the influence of HBI is negative on truck accidents
Un-signalised approaches	No model	No model		No model	No model	
Signalised approaches	Fixed parameter model including HBI , AADT, and two-lane indicator	No model	The prediction is not good	HBI and geometric model	No model	The prediction is not good

Table 10-17 continued

Two-lane approaches	No model	No model		No model	No model	
Three-lane approaches	A random parameter model including traffic and geometric variables	No model		A fixed parameters model with HBI and geometric variables	No model	Adding traffic HBI become insignificant
Grade-separated approaches	A random parameters model including HBI and geometric variables	No model	When traffic added to the model HBI become insignificant The overall fit of the model without HBI as input variable is better than this model	A fixed parameter model including only HBI	No model	Because the value of constant is high (12.8) so the model is not appropriate
At-grade approaches	A random parameter model including AADT, HBI , and geometric variables were identified		Better overall fit compared to the model without HBI The influence of HBI on total accidents is negative	A Fixed parameter model were identified including AADT, HBI , and geometric variables		Better overall fit compared to the model without HBIs as input variable The influence of HBI on truck accidents is negative

Conclusion

Based on the total accident summary results in Table 10-17, it can be concluded that at all approaches, HBIs can be used along with traffic and geometric variables to study accident risk. Note that the majority of HBIs (87%) occurred at approaches and that as HBIs increase, the number of total accidents increases. This result is in line with the study of Guo et al. (2010), who found that across the road network as near-miss accidents increase, total accidents increases, and Lee et al. (2007), who state that near-miss accidents are related to all types of accident. Note that in these studies, near-miss accidents included all types of manoeuvres, not only harsh braking manoeuvres. When considering HBI at approaches for improving safety of roundabout approaches, entry width in addition to other significant geometric variables should be considered as it was found to have significant positive effect on total accidents (higher entry width is associated with higher total accidents).

It can also be concluded that it is possible to develop a good predictive model for truck accidents at M-class approaches based on HBI, traffic, and geometric parameters. This model can be used for prioritising safety in these approaches in order to make the roundabouts safer.

It is concluded that a good model for normalised truck accidents by truck traffic percentage was acquired in A- and B-class approaches, but the influence of HBI was negative. It is concluded that this effect might indicate future accident risk in A- and B-class approaches.

For at-grade roundabouts when analysed separately, a good prediction was identified for total and truck accidents but the influence of HBI was negative (high HBI with low accident) and this is probably an indicator of high accident risks in these at-grade roundabouts, however, further investigation is required with a higher number of observations.

It can be concluded that for all the cases when the HBI were found to be significant along with traffic and geometric variables, the overall fit of the models was improved when compared to the model having only traffic and geometric as input variables.

Chapter 11 Conclusions and Recommendations

11.1 Summary and Conclusions

Accident rates have been falling for many years in the UK. Most locations with historically high observed accident rates have received some kind of safety measure. Therefore, the problem addressed by this thesis is the need for further alternative methods to identify and reduce the risk of accidents and to prioritise expenditure on road safety where it can have most effect. Consequently, this research aimed to analyse potentially unsafe truck driving conditions from records of HBIs that may indicate the location at which there is an increased risk of accidents. The research was based on total accidents, truck accidents, and HBIs of 70 roundabouts (284 approaches), using appropriate statistical models to determine the traffic and geometric factors influencing them. In addition, the HBI models were compared to the total accident and truck accident models, and HBIs were used as an independent variable, along with other traffic and geometric variables, to identify their relationship with total and truck accidents at different roundabout categories in order to achieve the aims and objectives of this thesis.

Literature Review

In **Chapter Two**, the thesis started with a review of the existing literature available for accidents, near-miss accidents, and HBIs. The following conclusions were drawn from previous studies:

- The numbers of accidents, deaths, and serious injuries have decreased over the last decades at both road segments and roundabouts, which support the thesis problem statement, restated a few sentences earlier.
- While the DfT (2014) provided reported contributory factors for accidents on road segments (Motorways, A roads, B roads, C and unclassified roads), no studies reported contributory factors for accidents specifically at roundabouts.
- As accidents are a count variable, non-negative, and discrete, NB models have been introduced by several authors to examine this data.
- Random-parameters count data models were introduced by several researchers to predict accident data, and it is concluded that if parameters are considered fixed across the observations, the result will be biased, and possibly, incorrect conclusions will be drawn with respect to the independent variables (Lord and Mannering, 2010).

- No studies applied random parameters models to roundabouts. This thesis, therefore, applies this approach for the first time to predict HBIs, total accidents, and truck accidents at roundabouts, based on geometric and traffic variables.
- Creating a predictive model based on only one variable (i.e only traffic volume) is not an appropriate course, as several possible wrong conclusions could be drawn because there are other factors that influence accidents, so the model with only one variable may be biased, as stated by Harper and Dunn (2005) who found that the accuracy of the predicted models improved when geometric variables were added.
- Studies have shown that accidents involving trucks are more dangerous than other accidents on road segments (e.g. DFT, 2014; Trucks V, 2013; US Department of Transportation, 2014; Carstensen et al., 2001; Grygier et al., 2007; Kennedy, 2007) because of their size, carrying load, their configuration, and their manoeuvres. The majority of fatalities would be the drivers and occupants of cars when accidents occur with trucks.
- Previous studies (Fazeen et al., 2012; Bayan et al., 2009; Dingus et al., 2005; Fitch et al., 2009; Greibe, 2007; Grygier et al., 2007; Harbluk et al., 2006; Inman et al., 2006; Klauer et al., 2006; Klauer et al., 2009; Simons-Morton et al., 2009; Benmimoun et al., 2011; Lee et al., 2007; Haque et al., 2016) were undertaken based on driver behaviour and their influence on recording near-miss accidents including HBIs, but based on the literature review no studies were undertaken on the influence of traffic and geometric characteristics on HBIs. Novel aspects of this study are to create a model which predicts HBIs based on these parameters, and to add HBIs as an independent variable along with the traffic and geometric characteristics to predict total and truck accidents at roundabouts.
- Previous studies have only rarely attempted to predict truck accident models with respect to traffic and geometric characteristics at roundabouts using NB models, the only model available is by Daniels et al. (2010), and ADT was the only variable seen to influence truck accidents. While in this study models estimated for truck accidents for whole roundabouts, within circulatory lanes, and at approaches and a number of geometric variables in addition to AADT and percentage of truck traffic were associated with the occurrence of truck accidents.
- No previous study has included truck percentage, signalisation, and type of grade at approaches as variables influencing total accidents, while these effects were addressed in this study and all were found to have a statistically significant effect on accidents.

- All previous studies which identified the influence of traffic volume (AASHTO, 2014; Daniels et al., 2010; Maycock and Hall, 1984; Guitchet, 1997; Harper and Dunn, 2005; Montella, 2007; Rodegerdts et al., 2007; Senk and Ambros, 2011; Arndt, 1998; Turner et al., 2006; Brude and Larsson, 2000), ICD (Retting, 2006; Rodegerdts et al., 2010; Maycock and Hall, 1984), entry width (Retting, 2006; Maycock and Hall, 1984; Kim et al., 2013; Rodegerdts et al., 2007), circulatory roadway width (Retting, 2006; Rodegerdts et al., 2007; Harper and Dunn, 2005; Kim et al., 2013), number of lanes (Brude and Larsson, 2000; Kim et al., 2013) and number of arms (Brude and Larsson, 2000; Kim et al., 2013) on total accidents at whole roundabouts, at entering/circulating, and at approaches, used fixed-parameters NB models and did not report marginal effects. This study uses the novel approach of analysing the marginal effects of the parameters' influence at roundabouts. In addition, in this study (thesis) random-parameters NB models were used to compare with fixed parameter NB models.

Methodology

In **Chapter Three**, the data description and methods were illustrated. Firstly, 70 roundabouts (with 284 approaches) with low and high occurrences of HBIs, located on motorways, and A, and B roads, were selected with different level of HBIs. HBI data were acquired from Microlise Ltd, accident data were acquired from the STATS19 database, geometric data were identified using the ruler in Google Earth, and traffic data were obtained from the Department of Transport website.

The decelerations of the HBIs that are used in this study were then compared with previous studies and with test truck trials undertaken at TRL. It was found that based on these studies (Olson et al., 2009; Fazeen et al., 2012; Benmimoun et al., 2011; Bayan et al., 2009; Dingus et al., 2006; Fitch et al., 2009; Greibe, 2007; Blanco et al. 2011;Grygier et al., 2007; Haque et al., 2016; Harbluk et al., 2007; Inman et al., 2006; Lee et al., 2007; Simons-Morton et al., 2009; Geotab Inc., 2015; OGP, 2014), the harsh braking longitudinal deceleration varies from a minimum value of 0.2 g (1.96 m/s^2) to a maximum value of 0.86 g (8.44 m/s^2) and differs with the type of vehicle and study. In this study (thesis), based on the Microlise Ltd definition, the HBI recorded at deceleration rates varies from 2.22 m/s^2 to 4.44 m/s^2 based on type/size of truck; and from the test truck undertaken in TRL using smartphone accelerometers it was found that the maximum longitudinal deceleration for a 3.5T truck is 8.55 m/s^2. Therefore, these decelerations are in line with previous studies.

Different procedures were undertaken for filtering and preparation of the data for different analysis and for modelling purposes which includes:

- Using Excel to KML, all HBI points were uploaded to Google Earth in order to select the locations and to count them for the purpose of analysis.
- Truck accidents were filtered from total accidents using the code and type of vehicle available in the STATS19 Excel sheet,
- Total and truck accident position coordination were converted to latitude/longitude from easting/northing using the Grid-InQuest program in order to upload them to Google Earth, and to count their numbers for approaches and within the circulatory lanes for the selected locations.
- Traffic data (AADT and percentage of truck traffic) for each approach of the selected roundabouts were collected from the Department for Transport website (DFT, 2016) using the county that the roundabout was located in and the code for each approach of the selected locations.
- For the grade-separated roundabouts a MATLAB program was used in order to estimate the amount of traffic for the approaches that are located in the direction of grade-separation.

In addition, in order to see if there are similar characteristics based on distance between accidents and HBIs for the selected roundabouts, number of accidents and HBIs were counted within 100m distance, beyond 100m distance from the entry line and within the circulatory lanes. In order to explore at what speed the trucks record harsh braking and how far from entry line of the approach, all the HBI data were filtered and distances were calculated for each point of HBI for the selected locations. All the geometric variables were measured using the Ruler from Google Earth, and also type of grade, signalisation, road marking, shape of the roundabout, and truck apron were identified from Google Earth. The accuracy of the Google Earth ruler was checked with a distance, Eq. (3-1), and with actual on-site tape measurements and found to be accurate. Regression analysis was used in order to identify the general trends of accidents and HBIs with traffic variables based on roundabout category.

Random-parameters NB models were used in order to identify the significance of traffic and geometric variables on accidents and HBIs, and to identify if there are similar trends for accidents and HBIs. Random-parameters models were compared to the fixed-parameter NB models, and the detailed procedures regarding random and fixed-parameters models were illustrated in this chapter. In addition, random- and fixed-parameters models were used to identify the relationship between total accidents and truck accidents, with HBIs along with traffic and geometric variables.

Total and Truck Accidents Trends

In **Chapter Four**, general total and truck accident trends for the studied roundabouts were described. The general summary and conclusions are:

- The number of total and truck casualties from 2002 to 2012 decreased by 37% and 35% respectively. On average, this decrease corresponds to general accident statistics on roads and at intersections (DfT, 2014; Trucks V, 2013; US Department of Transportation, 2014), and on roundabouts (Kennedy, 2007).
- The highest fatality proportions were recorded in each of the following situations: with a wet surface, at un-signalised roundabouts, at three-arm roundabouts, in rainy weather, at night, and at roundabouts serving M-class roads. It was further seen that this percentage is higher for truck accidents, and all these results were in line with the DfT (2014). It was also concluded that all the trends that were examined and illustrated in this chapter for the selected 70 roundabouts show typical accident characteristics.
- Driver/rider error or reaction is the most frequently recorded contributory factor at the selected roundabouts, as demonstrated in the results presented by the DfT (2014) for the years 2009 to 2013 for Motorways, A road, B roads, C and unclassified roads. In this respect, the selected roundabouts have typical accident characteristics.
- Most of the total accidents (60%), truck accidents (57%), and HBIs (75%) were recorded within 100m of the approach entry line. Geometric and traffic characteristics and road class meant that some locations had HBIs beyond 100m. A higher percentage (36%) of truck accidents occurred within the roundabout circulatory, compared to total accidents (32%) and HBIs (13%).

General Characteristics of HBI

In Chapter Six, general characteristics of HBIs were derived; they are:

A two pattern trend was observed when the speed of trucks while braking was related to the driveway distance from the entry of the roundabout. The first trend was for trucks that are braking at speeds of 0-20 km/h, and the second was for trucks that are braking at speeds greater than 20 km/h; as the trucks reach the entry line their speed decreases which is in line with the study of Qian et al (2015) who stated that drivers of passenger cars reduce their speed from 48 km/h to 21-30 km/h and to 11-20km/h while they are entering single-lane roundabouts.

- Relating speed to driveway distance for each approach separately reveals that a small number of the approaches show a one pattern trend. These approaches were un-signalised and had a low number of HBIs recorded at low speeds (0-20 km/h).
- The rate of truck harsh braking during peak and off-peak periods was found to be equal at signalised and un-signalised at-grade roundabouts, and a higher rate was found to occur during the peak period at both signalised and un-signalised grade-separated roundabouts. This indicates that HBIs in at-grade roundabouts are not related to traffic congestion, while this was true for grade-separated roundabouts. Using a linear relationship Lee et al. (2007) have found at intersections that 45% and 50% of near-miss accidents and HBIs, respectively, were recorded in congested traffic.

Regression Analysis

In **Chapter Four** and **Chapter Six,** the rates of accidents and HBIs were identified based on the number of lanes, number of legs, traffic control, and signalisation for different roundabout categories. It was found that for HBIs at whole roundabouts partially signalised roundabouts showed the highest rate, but this rate was very close to that of signalised roundabouts. For total and truck accidents, signalised roundabouts showed the highest rate, but the rate was very close to that of partially signalised roundabouts. Grade-separated roundabouts recorded higher rates of accidents and HBIs, relative to at-grade roundabouts. However, there was only a small difference between the rates of HBIs for whole roundabouts. Whether at-grade or grade-separated, similarly there was little difference between HBI rates for approaches to at-grade or grade-separated roundabouts.

From the regression analysis of the relationship between total accidents and truck accidents, to AADT and percentage of truck traffic carried out and illustrated in **Chapter Four** and from the relationship between HBIs to AADT and percentage of truck traffic illustrated in **Chapter Six**, it was found that:

Accidents (total and truck) and HBIs both showed a linear relationship with AADT with respect to number of lanes (two and three), type of grades (at-grade and grade-separated) and traffic control (partially signalised). Not all the geometric characteristics showed similar linear relationships of the three events to percentage of truck traffic.

The following conclusions can be drawn:

- Grade-separated roundabouts and at-grade roundabouts show different trends for all cases. For this reason, a NB model for each type of grade, based on different traffic and geometric characteristics, is necessary.

- Un-signalised and two-lane roundabouts showed a different trend from three-lane, signalised and partially signalised roundabouts, and for this reason an assessment of the effect of these variables on accidents using a NB distribution was undertaken. In addition, the different numbers of arms show different trends, so their effect is also identified using NB models.

Traditional Flow and Flow-Geometric Model

In the model development illustrated in **Chapter Five**, a flow model and flow-geometric model were identified using traditional NB models and the results were compared with previous studies. In each model, the number of observations, the country the study had been undertaken in, the year of study, the geometric variables, and the roundabout category, were all found to be different from this study, except for Maycock and Hall (1984), whose study was undertaken in the UK. The summary of the results and conclusions are as follows:

- Overall fit of the thesis model was improved when geometric variables were added to the traffic variables which support the findings of Harper and Dunn (2005).
- The flow model was in line with previous studies (Maycock and Hall, 1984; Guichet, 1997; Montella, 2007; Persaud et al., 2001; Harper and Dunn, 2003; Turner et al., 2006; Brude and Larsson, 2000; Šenk and Ambros, 2011; Daniels et al., 2010; Arndt, 1998; Rodegerdts et al., 2007) and showed that AADT has a statistically significant positive effect, increasing total accident numbers.
- The flow-geometric models illustrate that some of the variables found to have a significant effect on accident numbers were also found by previous researchers to have an effect, for instance, ICD by Rodegerdts et al. (2007), and the number of lanes at approaches by Kim et al. (2013).
- Previous studies, for instance, Maycock and Hall (1984), identified accident models for entering/circulating and for approaches, Rodegerdts et al. (2007) for entering/circulating, for exiting/circulating and for approaches, and Kim et al. (2013) for approaches, while models for whole roundabouts (entry and circulatory) were identified by Harper and Dunn (2003), Daniels et al. (2010), Guichet (1997), Montella (2007), and Arndt (1998). In the study reported in this thesis, total and truck accident models were identified for the whole roundabouts (entry and circulatory), within the circulatory lanes, and at the approaches.

Random vs Fixed Parameters NB Model

From the models identified in **Chapters Five and Seven**, the following conclusions are drawn:

- For all roundabout categories random-parameters models best fitted the data except for truck accidents at at-grade locations when analysed separately. For this category a fixed model was identified because all the variables were found to have a statistically fixed effect across the observations.
- The random-parameters models were found to be better models for predicting accident and HBI numbers because they identify more significant variables, give better fits to the data (as indicated by the relationship between predicted and actual values) and because, for the random parameters identified, they provide information about the number of observations that have a positive or negative effect.

<u>Accidents and HBIs Models</u>

Based on these results identified in **Chapters Five and Seven, and Chapter Eight** the following conclusions can be drawn:

- It is concluded that un-signalised and three-arm roundabouts have lower numbers of truck and total accidents, although the accidents are considered more severe with regard to the fatality percentage. Kennedy (2007) found a higher percentage of fatalities and serious injuries were recorded in three-arm compared with four-arm roundabouts. While the majority of three-arm roundabouts recorded higher rates of HBIs relative to six-arm roundabouts, the probable reason for this is the high percentage of truck traffic at these three-arm roundabouts.
- The fact that un-signalised roundabouts and un-signalised circulatory lanes experience fewer accidents and HBIs may not be because signals cause accidents, but because roundabouts and circulatory lanes without signals are generally those carrying less traffic which, therefore, has fewer opportunities for traffic conflicts. When accidents and HBIs were related to AADT based on traffic control type, un-signalised roundabouts showed fewer accidents and HBIs with lower traffic levels (i.e. AADT).
- At signalised roundabouts where more HBIs occur, it is probably because the drivers in some cases could not catch the green light and stopped suddenly at a high deceleration rate, as stated by Inman et al. (2006). In addition, Harbluk et al. (2007) found that 85% of HBIs occurred at signalised intersections. Because the effect of signalised roundabouts varied across the roundabouts, it is appears that there are other factors like AADT, percentage of truck traffic, geometric variables in addition to driver behaviour influences HBI occurrences.
- At-grade un-signalised roundabouts recorded higher number of HBIs because of high percentage of truck traffic.

- That some approaches that are located on grade-separated roundabouts see more HBIs is because these locations have high percentages of truck traffic and the majority of them are signalised.
- At-grade roundabouts are safer than grade-separated roundabouts, as all the variables that were found to be random and showed low numbers and rates of accidents and HBIs were found at at-grade roundabouts.
- The majority of un-signalised roundabouts, un-signalised circulatory lanes, lower ICDs, and at-grade approaches were all shown to have lower numbers of accidents and HBIs than at partially signalised roundabouts. The majority of roundabouts with these characteristics were at-grade. The majority of the variables that were found to be random and varied across the observations, with a positive effect (increasing) on total and truck accident numbers and on (increasing) HBI numbers, were located at grade-separated, partially signalised roundabouts, and partially signalised circulatory lanes.

Comparison between HBIs and Accidents

- For whole roundabouts including for grade-separated and at-grade roundabouts when analysed separately, and for approaches, increased AADT leads to higher total accidents and truck accidents, and HBIs.
- ICD has a statistically significant influence on accidents (total and truck), and on HBIs but based on marginal effects it can be concluded that its influence over 11 years and over two years is not high. In addition it was found that there is a big similarity between the influence of the other geometric variables on total accidents, truck accidents, and HBIs based on marginal effect some considered important while some were not because of low marginal effect.
- The most important variables were AADT and percentage of truck traffic, which were found to have a positive influence on accidents and HBIs. Regarding the geometric variables signalisation, circulatory roadway width, number of arms, and two-lane indicator are considered the most important factors influencing accidents and HBIs.

Based on the model comparison it can be concluded that:

HBIs are influenced by traffic and geometric variables in a similar way to total and truck accidents. They may therefore, be useful in considering accident risk at roundabouts. They are a source of much more numerous data than accidents and this may be important in considering changes or trends in accident risk over a much shorter time than actual accidents records.

Design Considerations

The results of Chapter Five and Chapter Seven were compared with DMRB TD 16/07(2007), and it was found that some approaches have entry widths higher than the design limit, and some of these approaches have low traffic volumes. Circulatory roadway width was within the design limit. DMRB TD 16/07(2007) recommends that locations with high ICD should be signalised because they have high traffic volumes, but there are a number of roundabouts in this study that are partially signalised, so they require reassessment. The majority of the selected roundabouts have oval shape and they have higher rate of total accidents, truck accidents and HBIs, than circular shape roundabouts because they are grade-separated roundabouts with high traffic flow.

For the selected locations road markings were investigated and the results compared with DMRB TA 78/97(1997). Large roundabouts with circular markings require reassessment because they recorded higher rates of accidents and HBIs. They may need more complicated marking such as concentric-spiral and spiral markings. On the other hand, some small roundabouts with spiral markings recorded high rates of accidents and HBIs. Spiral markings, according to DMRB TA 78/97(1997), are more appropriate for big roundabouts, so these small roundabouts require concentric markings.

Accidents and HBIs along with Traffic and Geometric Variables

In order to achieve the main aim of this study – to identify locations of high accident risk based on truck sensor data (HBIs) – HBIs were used as an independent variable for predicting total and truck accidents along with traffic and geometric variables as described in **Chapter Ten**. In summary:

- For whole roundabouts, within circulatory lanes, at approaches, and at grade-separated roundabouts, a significant linear relationship was identified between total and truck accidents and HBIs. However, based on a low value of R^2, practically the relationship is not marked. This relationship was found to be insignificant for at-grade roundabouts and the probable reason is due to lower total and truck accidents relative to HBIs.
- As a NB model is more appropriate for count data, random and fixed-parameters NB models were used to identify the relationship between accidents and HBIs along with traffic and geometric variables.

- The models identified for total and truck accidents, at whole roundabouts, at grade-separated roundabouts, and at a number of approach categories were found to have a lower overall fit compared to the models without having HBI as an input variable. At all approaches, when HBI was included as an input variable to predict truck accidents, this did not improve the overall fit of the model compared to that without HBI as an input variable. Traffic variables in these locations showed a larger impact on truck accidents than HBIs. However, within circulatory total and truck accidents related to HBIs, but geometric variables have a larger impact on accident occurrence, and the model without HBI has a better overall fit than the model with HBI.
- Random-parameters models including HBI, traffic and geometric variables were identified for total accident numbers at all approaches; at three-lane approaches when analysed separately from all approaches, and for normalised total accidents at M-class approaches when analysed separately from all approaches. A random-parameters model was identified for M-class approaches when truck accidents are related to HBIs along with traffic and geometric variables. All of these models were compared to the model without HBI as an input variable; it was found that adding HBI to the model along with traffic and geometric variables improves the overall fit of the model.
- Random parameter model for normalised truck accidents by truck traffic percentage were acquired in A- and B-class approaches, but the influence of HBI was negative. The influence of HBI was also negative on total and truck accidents at at-grade roundabouts.

From the results of **Chapter Ten** the following conclusions can be drawn:

- It can be concluded that based on total accidents, at all approaches, M-class, and three-lane approaches when analysed separately from all approaches, HBIs can be used along with traffic and geometric variables to prioritise safety measures at roundabout approaches, and for different approach categories. When considering HBI at approaches for improving safety of roundabout approaches, entry width in addition to other significant geometric variables should be considered as it was found to have significant positive effect on total accidents.
- For at-grade roundabouts the negative sign of HBI on total and truck accidents may be an indicator of high accident risks in these locations, however, further investigation is required with a higher number of observations.

- The models that are identified for M-class approaches based on truck accidents along with HBIs, traffic, and geometric parameters can be used for prioritising safety measures at these approaches such as controlling signalisation which influences the controlling amount of traffic, and based on HBI numbers which can be used as an indicator for predicting accident numbers at these locations.
- As the effect of HBIs was found to be negative on truck accidents at A- and B-class approaches when analysed separately from all approaches, it is concluded that this affect might indicate future accident risk in A- and B-class approaches.
- Considering:

  a) The random-parameters models that are identified for total accidents at all approaches, based on HBI along with traffic and geometric variables;

  b) The random-parameters model that are identified for normalised total accidents at M-class approaches when analysed separately from all approaches based on HBI along with traffic and geometric variables;

  c) The random-parameters models that are identified for truck accidents for M-class approaches based on HBIs along with traffic and geometric variables;

  d) The random-parameter models that are identified for truck accidents for A- and B-class approaches based on HBIs along with traffic and geometric variables, and

  e) Models that are identified by previous studies;

it can be concluded that no previous studies have investigated the relationship between total and truck accidents with HBIs along with traffic and geometric characteristics.

Previously, Guo et al. (2010) in a 100 car study at road sections, used Poisson regression, with only near-miss accidents included as an input variable but the fitness of the model was not shown. They found that as near-miss accidents increase, total accidents increase, with their definition of near-miss accidents including all types of manoeuvres, not only harsh braking manoeuvres. And Lee et al. (2007) related near-miss accidents using a linear relationship at intersections with respect to weather condition, traffic congestion, road alignment, traffic lanes, lighting condition, and driver seat belt use; they state that near-miss accidents are related to total accidents. These studies were for individual vehicles and low numbers of observations. The present method has big improvements because

I. It used the HBIs from 8000 trucks;

II. Separate random parameters NB models, were identified for HBIs, and compared with total and truck accident models;

III. Random and fixed parameters NB model were obtained for total and truck accidents based on HBI as input variable, along with traffic and geometric variables, with respect to many types of geometric roundabout categories; and

IV. A detailed analysis including the fitness of the models was reported.

Overall Conclusions

- Based on the results of this study, HBIs are influenced by traffic and geometric variables in a similar way to total and truck accidents. They may therefore, be useful in considering accident risk at roundabouts. They are a source of much more numerous data than accidents and this may be important in considering changes or trends in accident risk over a much shorter time than for accident data. It is concluded that the models for estimating total accidents, truck accidents and HBIs can be used by highway authorities to identify characteristics that may influence the number of accidents, in order to prioritise maintenance budget at certain locations. It should be taken into account that as truck accidents cost more than other vehicle accidents, when they do occur, it is important to give due emphasis to locations that have higher numbers of trucks and higher risk of truck accidents. In this study trucks accounted for 26.6% of all vehicles involved in accidents. The fatality proportion for truck accidents is much higher than for other vehicle types: 2.1% of truck accidents included a fatality, while the figure was 1.07% for accidents involving only other types of vehicles. This result supports previous findings (DFT, 2014; Trucks V, 2013; US Department of Transportation, 2014; Carstensen et al., 2001; Grygier et al., 2007; Kennedy, 2007). Trucks are an important factor for consideration when designing a road network, including roundabouts, even if the percentage of trucks is not high compared with other vehicle types, as when truck accidents occur, they result in for more severe outcomes. The size, weight and the configuration of a truck are all potential causes of severe accidents.
- HBIs can be used as a partial surrogate variable for accidents when considering safety at roundabout approaches, three-lane approaches, and M-class approaches along with traffic and geometric variables. This may become increasingly important as the number of accidents continues to fall and accident prediction based on study of historic accident patterns become less reliable as a result.
- Application of the random-parameters approach is considered a better approach for predicting accidents and HBIs at roundabouts, because it gives a better prediction of the events; more variables were found to be significant and; this approach gives information about whether the variable should be considered fixed or varied across the observations.

When a variable is found to vary across observations, it is an indicator of unobserved heterogeneity and indicates that the variable was not the main influence on the accidents or HBIs, it is probably other factors that are unavailable for the analysis when the accident or HBI occur which may cause this variation.

11.2 Limitations and Recommendations for Future Research

A limitation of this study is that only the HBI records from one client of Microlise Ltd were included. In addition, last speed reading is available for the HBIs and could be included as an additional variable, which is not available in the accident data. In this way, analysis of the HBIs could add information which could not be considered just from analysing accident data. A more complete study might be possible if additional data were collected by Microlise Ltd, for instance: initial speed of the harsh braking incident or length of the journey. For example, having the initial speed in addition to the last speed reading that is already available would allow the rate of deceleration to be computed, which might indicate the severity of the HBI.

The following presents recommendations for roundabout design and further work that can be done in the future:

- As identified in Chapter Four, un-signalised and three-arm roundabouts have the highest fatality percentage even if the accident numbers are not high, and it is recommended that further investigation be undertaken, including more observations of these types of roundabout.
- In Chapter Four, wet pavements and the night are seen to be associated with the highest fatality percentage with the lowest accident rates, so further investigation is required to identify the number of hours for which the roads are wet, in order to explore the rate of fatalities on wet and dry pavements.
- In Chapter Four, the trends for types of casualties were identified. It is recommended that random-parameters NB models are applied to study roundabout accidents in terms of casualty type (fatality, serious, and slight injury) for total and truck accidents.
- According to the results in Section 6.3, some approaches showed a one pattern trend in HBIs, between speed and distance from entry line. While most showed a two pattern trend. It is essential to investigate driving behaviour, specifically when harsh braking occurs, in order to enhance HBI models, and investigate accidents at these locations.
- For whole roundabouts, and at roundabouts approaches, the rate of HBIs at at-grade roundabouts is close to the rate of HBIs at grade-separated roundabouts. As the number of at-

grade roundabouts studied is low, so further investigation is required with a higher number of at-grade roundabouts.

- In Chapter Five, Section 5.9, the percentage of truck traffic was found to have an insignificant influence on truck accidents at at-grade roundabouts; however, as the number of observations was low (19 roundabouts) further investigations are required, including higher numbers of roundabouts, to find the influence of the percentage of truck traffic on truck accidents at at-grade roundabouts.
- In Chapter Five and Chapter Seven, it was found that higher circulatory roadway width contributes to a lower number of truck accidents and HBIs. It is recommended that a study is undertaken on the behaviour of drivers and the impact of this geometric parameter on them while they are travelling across roundabouts. This may lead safer to design geometrics for roundabouts handling significant truck traffic flows.
- In Chapter Seven, Section 7.3, it was found that four and five-arm grade-separated roundabouts have higher numbers of HBIs relative to six-arm roundabouts. Because only seven six-arm roundabouts were included in this study, it is recommended that more observations of six-arm roundabouts are made, to find their influence on HBIs with other geometric and traffic variables, compared to roundabouts with fewer arms.
- Speed data for accidents and road surface characteristics (pavement condition including skid resistance) for accidents and HBIs were not available in this study, and their effects on truck accidents and truck HBIs are important, as seen in the literature in which pavement condition highly influences the overturning of trucks. As such, it is recommended that predictive models be created that includes these data for truck accidents and HBI to improve the prediction of truck accidents within the circulatory lanes, and at roundabout approaches.
- This study was based on roundabouts, and significant results were identified based on HBIs, so it is suggested that other research is required studying HBIs on rural and urban highways and at other types of intersections. It is also recommended that random-parameters NB count data models be applied for the prediction of total accidents, truck accidents, and HBIs across the roadway segments and intersections.

In reality it is difficult for highway authorities who are responsible for maintenance and safety issues at roundabouts to change the number of lanes or arms, as these all require a large investment. But as stated by DMRB TD 16/07 (2007) for existing roundabouts, entry width, and circulatory roadway width can be reduced, either physically by adding textured colouring to splitter island or by adding kerbs. Based on the model results in Chapter Five and Chapter Seven, it is essential that design of new roundabouts must consider future traffic flow, lower numbers of arms, and whether they should be signalised or un-signalised based on the amount of traffic in the area. However, roundabouts can be designed with higher measured width based on future traffic volume while using textured colouring or adding kerb so as to reduce the entry width at the beginning service of roundabouts when flows are lower. This is because based on modelling results, higher entry width was associated with higher accidents and HBIs at approaches. Note that lower number of arms (three and four arms) are preferred for roundabouts because they are associated with lower accidents probably because of lower numbers of conflicts and other geometric variables illustrated in this study, and because roundabouts with lower numbers of arms provide better deflection for the driver: adequate deflection is difficult to achieve with more than three arms (DMRB TD 16/07, 2007). It should be taken into account that in this study a higher percentage of people were killed because of truck accidents at three-arm roundabouts relative to four, five, and six-arm roundabouts and Kennedy (2007) found a higher percentage of fatalities and serious injuries recorded in three-arm compared with four-arm roundabouts. This means that while three-arm roundabouts decrease truck accidents, when they do occur they are more severe than at four-arm roundabouts, so as regards truck accidents, it is safer to design a roundabout based on four-arms or designing a roundabout with three-arms but with improved geometric characteristics and probably other improvements which is outside the scope of the study that could be taken into account; for instance training and educating truck drivers regarding the severity of accidents at three-arm and un-signalised roundabouts, by adding more signs in these locations, changing speed limit, etc.

- Signalisation control is in the hands of highway authorities. Based on the high number of total and truck accidents within roundabout circulatory lanes, a recommendation could be to remove partial signalisation within the circulatory of the roundabouts, and either make the circulatory fully signalised or un-signalised. However, signalisation may be decided for reasons of traffic management, so partially signalised locations need further study and investigation.
- Based on the impact of signalisation on HBIs, as illustrated in Chapter Seven, more investigations are required to explore the relationship between driver behaviour and HBIs in signalised, un-signalised, and partially signalised roundabouts.

- Where the design guide has not been followed, there appeared to be a high rate of accidents and HBIs per roundabout recorded in some small roundabouts; furthermore, the big roundabouts with concentric markings recorded higher rates of accidents and HBIs. It is recommended that designers revisit and re-assess marking.
- As the relationship between truck accidents and total accidents with HBIs was found to be negative for at-grade roundabouts (illustrated in Section 10.1.4.2), it is recommended that this effect be studied, including through more observation.
- The models identified for total and truck accidents without having HBI as an input variable, at whole roundabouts, at grade-separated roundabouts, and for total and truck accidents, in addition to A- and B-class approaches for total accidents showed a better fit compared to the models with HBI as input variable. In two-lane approaches and in un-signalised approaches, HBI was not related to total and truck accidents. Therefore, further study is recommended to examine longer-term trends in HBI numbers, which may reveal changes in safety risks (including other measures such as including telematics data from other trucks).
- The percentage of harsh braking within circulatory section is small (13%) and their influence will be insignificant when geometric variables are added to the model of HBI and traffic, probably because in the curved section of circulatory lanes harsh cornering events may occur. Therefore, it is recommended to study the influence of harsh braking with harsh cornering on total and truck accidents within the circulatory section.

References

ALPHAND F, NOELLE U and B GUICHET, 1991B. Roundabouts and Road Safety; State of the Art in France. Intersections without Traffic Signals II. Proceedings of an International Workshop 18-19 July 1991 in Bochum, Germany, pp126-140.

ALLURI, P. 2008. *Assessment of potential site selection methods for use in prioritizing safety improvements on Georgia roadways*, ProQuest.

AASHTO, 2014. Highway Safety Manual. American Association of State Highway and Transportation Officials, Washington, D.C.

ANASTASOPOULOS, P. C. & MANNERING, F. L. 2009. A note on modelling vehicle accident frequencies with random-parameters count models. *Accident Analysis & Prevention,* 41**,** 153-159.

ANDERSSON, J. 2008. Vehicle dynamics: optimization of Electronic Stability Program for sports cars.

ARNDT O K. 1991. Roundabout Safety Study: Effect of Geometry on Accident Rate. Queensland Department of Transport, Transport Technology Division. Report DSB01.

ARNDT, O. & TROUTBECK, R. 1998. Relationship between roundabout geometry and accident rates. *Transportation research circular***,** 28: 1-16.

AUSTROADS, 1993. Guide to Traffic Engineering Practice, Part 6—Roundabouts. Sydney, Australia: Austroads

BAYAN, F. P., CORNETTO III, A. D., DUNN, A. & SAUER, E. 2009. Brake timing measurements for a tractor-semitrailer under emergency braking. *SAE paper***,** 01-2918.

BHAT, C. R. 2001. Quasi-random maximum simulated likelihood estimation of the mixed multinomial logit model. *Transportation Research Part B: Methodological,* 35**,** 677-693.

BHAT, C. R. 2003. Simulation estimation of mixed discrete choice models using randomized and scrambled Halton sequences. *Transportation Research Part B: Methodological,* 37**,** 837-855.

BENMIMOUN, M., FAHRENKROG, F., ZLOCKI, A. & ECKSTEIN, L. 2011. Incident detection based on vehicle CAN-data within the large scale field operational test "euroFOT". *In:* 22nd Enhanced Safety of Vehicles Conference (ESV 2011), Washington, DC/USA.

BELSLEY, DAVID A., EDWIN KUH, AND ROY E. WELSCH. 1980. Regression Diagnostics: Identifying Influential Data and Sources of Collinearity. New York: John Wiley.

BIERNBAUM, L., GAY, K. & LEE, D. B. 2008. Safety Model Assessment and Two-Lane Urban Crash Model.

BLANCO, M., HANOWSKI, R. J., OLSON, R. L., MORGAN, J. F., SOCCOLICH, S. A. & WU, S.-C. 2011. The Impact of Driving, Non-driving Work, and Rest Breaks on Driving Performance in Commercial Vehicle Operations.

BRUNSON, S., KYLE, E., PHAMDO, N., & PREZIOTTI, G. 2002. Alert algorithm development program --NHTSA rear-end collision alert algorithm – Final report. Report No. DOT-HS-809526. Washington, DC: National Highway Traffic Safety Administration.

BRUDE, U., LARSSON, J., 2000. What roundabout design provides the highest possible safety? Nordic Road and Transport Research, 2000(2), 17-21.

BYRNE, M., PARRY, T., ISOLA, R. & DAWSON, A. 2013. Identifying road defect information from smartphones. *Road & Transport Research: A Journal of Australian and New Zealand Research and Practice,* 22**,** 39.

CARLSSON, F. & MARTINSSON, P. 2007. Willingness to pay among Swedish households to avoid power outages: a random parameter Tobit model approach. *The Energy Journal***,** 75-89.

CARSTENSEN AF GITTE, WINNIE HANSEN, VICTOR HOLLNAGEL, HUGO HØJGAARD, IB JENSEN, PETER KINES, LARS KLIT, PALLE KOFOED, JAN B. MIKKELSEN OG KURT PETERSEN, 2001. Analysegruppen for Vejtrafikuheld (*AVU*), Lastbiluheld- en dybdeanalyse af 21 uheld.

CARSTEN, O., KIRCHER, K. & JAMSON, S. 2013. Vehicle-based studies of driving in the real world: The hard truth? *Accident Analysis & Prevention,* 58**,** 162-174.

COOK, J. & FREUDENBERG, J. 2007. Controller Area Network (CAN). EECS.

DANIEL, J. & CHIEN, S. I.-J. 2004. Truck safety factors on urban arterials. *Journal of Transportation Engineering,* 130**,** 742-752.

DANIELS, S., BRIJS, T., NUYTS, E. & WETS, G. 2010. Explaining variation in safety performance of roundabouts. *Accident Analysis & Prevention,* 42**,** 393-402.

DEPARTMENT FOR TRANSPORT 2012. Reported Road Casualties in Great Britain: Main Results 2011, Statistical Release.

DEPARTMENT FOR TRANSPORT 2013. Reported Road Casualties in Great Britain, Annual Report, Statistical Release.

DEPARTMENT FOR TRANSPORT 2014. Reported Road Casualties in Great Britain, Annual Report, Statistical Release.

DEPARTMENT OF MAIN ROADS 2006. Chapter 14: Roundabouts. Road Planning and Design Manual

DEPARTMENT FOR TRANSPORT 2009. Signal controlled roundabout, Local Transport Note 1/09.

DEPARTMENT FOR TRANSPORT 2015. Road Traffic Estimates: Great Britain 2014 (R), Statistical Release.

DFT 2016. *Department for Transport, Traffic Counts*. Available at: http://www.DfT.gov.uk/traffic-counts/area.php/ [Accessed 10 Aug. 2016].

DESIGN MANUAL OF ROADS AND BRIDGES, TD 16/07, 2007. Geometric Design of Roundabouts, London, UK.

DESIGN MANUAL OF ROADS AND BRIDGES, TA 78/97, 1997. Design of Road Markings at Roundabouts, London, UK.

DICKERSON, A., PEIRSON, J. & VICKERMAN, R. 2000. Road accidents and traffic flows: an econometric investigation. *Economica,* 67**,** 101-121.

DINGUS, T. A., KLAUER, S., NEALE, V., PETERSEN, A., LEE, S., SUDWEEKS, J., PEREZ, M., HANKEY, J., RAMSEY, D. & GUPTA, S. 2006. The 100-car naturalistic driving study, Phase II-results of the 100-car field experiment.

DONG, C., CLARKE, D. B., YAN, X., KHATTAK, A. & HUANG, B. 2014. Multivariate random-parameters zero-inflated negative binomial regression model: An application to estimate crash frequencies at intersections. *Accident Analysis & Prevention,* 70**,** 320-329.

EL-BASYOUNY, K. & SAYED, T. 2009. Accident prediction models with random corridor parameters. *Accident Analysis & Prevention,* 41**,** 1118-1123.

ELVIK, R. 2003. Assessing the validity of road safety evaluation studies by analysing causal chains. *Accident Analysis & Prevention,* 35**,** 741-748.

Earth Point 2016. *Excel To KML - Display Excel files on Google Earth*. Available at: https://www.earthpoint.us/ExcelToKml.aspx/ [Accessed 10 Aug. 2016].

FAZEEN, M., GOZICK, B., DANTU, R., BHUKHIYA, M. & GONZÁLEZ, M. C. 2012. Safe driving using mobile phones. *Intelligent Transportation Systems, IEEE Transactions on,* 13**,** 1462-1468.

FABER, F., JONKERS, E., AUST, M., BENMIMOUN, M., REGAN, M., JAMSON, S. & DOBBERSTEIN, J. 2011. Analysis methods for user related aspects and impact assessment on traffic safety, traffic efficiency and environment. *euroFOT DL6.*2.

FITCH, G., LEE, S., KLAUER, S., HANKEY, J., SUDWEEKS, J. & DINGUS, T. 2009. Analysis of lane-change crashes and near-crashes. *US Department of Transportation, National Highway Traffic Safety Administration*.

FLANNERY, D. J. & O'DONOGHUE, C. 2009. Participation in higher education: a random parameter logit approach with policy simulations.

FRIDSTRØM, L., IFVER, J., INGEBRIGTSEN, S., KULMALA, R. & THOMSEN, L. K. 1995. Measuring the contribution of randomness, exposure, weather, and daylight to the variation in road accident counts. *Accident Analysis & Prevention,* 27**,** 1-20.

GÅRDER, P. 1998. Little Falls, Gorham—A Modern Roundabout. *Maine Department of Transportation, Bureau of Planning, Research & Community Services, Transportation Research Division, Final Report, Technical Report*.

GARNOWSKI, M. & MANNER, H. 2011. On factors related to car accidents on German Autobahn connectors. *Accident Analysis & Prevention,* 43**,** 1864-1871.

GEOTAB INC. 2015. *Geotab Management by Measurement*. Available at: https://www.geotab.com/.

GINGRICH, M. & WADDELL, E. 2008. Accommodating Trucks in Single and Multilane Roundabouts. *In:* Transportation Research Board, National Roundabout Conference, Kansas City, 12-18.

GREENE, W. 2007. *LIMDEP* 9.0 reference guide. *Plainview, NY: Econometric Software Inc.*

GREIBE, P. 2007. Braking distance, friction and behaviour. *Findings, analyses and recomendations based on braking trials.[Brzdná dráha, trenie a správanie sa. Zistenia, analýzy a odporúčania založené na brzných skúškach]. Lyngby: Trafitec*.

GRYGIER, P. A., GARROTT, W. R., SALAANI, M. K., HEYDINGER, G. J., SCHWARZ, C., BROWN, T. & REYES, M. 2007. Study of heavy truck air disc brake effectiveness on the national advanced driving simulator. *In:* The 20th ESV Conference Proceedings.

GUICHET, B. 1997. Roundabouts in France: Development, safety, design, and capacity. *In:* Third International Symposium on Intersections without Traffic Signals.

GUO, F., KLAUER, S. G., MCGILL, M. T. & DINGUS, T. A. 2010. Evaluating the relationship between near-crashes and crashes: Can near-crashes serve as a surrogate safety metric for crashes?

HARBLUK, J. L., NOY, Y. I., TRBOVICH, P. L. & EIZENMAN, M. 2007. An on-road assessment of cognitive distraction: Impacts on drivers' visual behaviour and braking performance. *Accident Analysis & Prevention,* 39**,** 372-379.

HARPER, N. J. & DUNN, R. 2005. Accident prediction models at roundabouts. *In:* ITE 2005 Annual Meeting and Exhibit Compendium of Technical Papers.

HARPER, N. J. & DUNN, R. C. 2003. Accident prediction at urban roundabouts in New Zealand-some initial results. *In:* Proceedings 26th Australasian Transport Research Forum October 2003, Wellington.

HAQUE, M., OVIEDO-TRESPALACIOS, Ó., DEBNATH, A. K. & WASHINGTON, S. 2016. Gap acceptance behavior of mobile phone distracted drivers at roundabouts. *Transportation Research Record*.

HESS, S., POLAK, J. W. & DALY, A. 2003. On the performance of the shuffled Halton sequence in the estimation of discrete choice models. *In:* European Transport Conference, Strasbourg, Citeseer.

HISELIUS, L. W. 2004. Estimating the relationship between accident frequency and homogeneous and inhomogeneous traffic flows. *Accident Analysis & Prevention,* 36**,** 985-992.

INMAN, V. W., DAVIS, G. W., EL-SHAWARBY, I. & RAKHA, H. A. 2008. Test Track and Driving Simulator Evaluations of Warnings to Prevent Right-Angle Crashes at Signalised Intersections.

ISEBRANDS, H. 2009. Crash analysis of roundabouts at high-speed rural intersections. *Transportation Research Record: Journal of the Transportation Research Board***,** 1-7.

IVAN, J. & O'MARA, P. 1997. Prediction of traffic accident rates using Poisson regression. *In:* 76th Annual Meeting of the Transportation Research Board.

JACQUEMART, G. 1998. Synthesis of Highway Practice 264: Modern Roundabout Practice in the United States, National Cooperative Highway Research Program. National Academy Press, Washington, DC.

JAMSON, S., WARDMAN, M., BATLEY, R. & CARSTEN, O. 2008. Developing a driving Safety Index using a Delphi stated preference experiment. *Accident Analysis & Prevention,* 40**,** 435-442.

JOSHUA, S. C. & GARBER, N. J. 1990. Estimating truck accident rate and involvements using linear and Poisson regression models. *Transportation planning and technology,* 15**,** 41-58.

KAMIŃSKA, J. 2014. Choice of Functional Form for Independent Variables in Accident Prediction Models. *Logistics and Transport,* 21**,** 51-62.

KEMP, R., CHINN, B. & BROCK, G. 1978. Articulated vehicle roll stability: methods of assessment and effects of vehicle characteristics.

KENNEDY, J. 2007. *International comparison of roundabout design guidelines*, TRL.

KIM, S. & CHOI, J. 2013. Safety analysis of roundabout designs based on geometric and speed characteristics. *KSCE Journal of Civil Engineering*, 17**,** 1446-1454.

KIMBER, R. 1980. The traffic capacity of roundabouts. Transport and Road Research Laboratory, Department of the Environment, Department for Transport, TRRL Laboratory Report 942.

KESSLER, C. ETEMAD, A. Alessandretti, G. Heinig, K. Selpi, Brouwer, R. Cserpinszky, A. Hagleitner, W. Benmimoun M. 2012. euroFOT-European Large-Scale Field Operational Test on In-Vehicle Systems. *euroFOT DL11.3*.

KLAUER, S. G., DINGUS, T. A., NEALE, V. L., SUDWEEKS, J. D. & RAMSEY, D. J. 2006. The impact of driver inattention on near-crash/crash risk: An analysis using the 100-car naturalistic driving study data.

KLAUER, S. G., DINGUS, T. A., NEALE, V. L., SUDWEEKS, J. D. & RAMSEY, D. J. 2009. Comparing Real-World Behaviors of Drivers with High Versus Low Rates of Crashes and Near Crashes.

KLAUER, S. G., GUO, F., SUDWEEKS, J. & DINGUS, T. A. 2010. An analysis of driver inattention using a case-crossover approach on 100-car data: Final report. US Department of Transportation, DOT HS, 811 334.

KOWDLA, S. 2004. *Modeling crash frequencies at signalized intersections in central Florida.* University of Central Florida Orlando, Florida.

LEE, S., LLANERAS, E., KLAUER, S. & SUDWEEKS, J. 2007. Analyses of rear-end crashes and near-crashes in the 100-car naturalistic driving study to support rear-signaling countermeasure development. *DOT HS,* 810 846.

LENTZ, 2008. *Geographic Coordination System Conversations.* Available at: http://jenniferalentz.info/Teaching/Tutorials/CoordinateConversions.pdf/[Accessed 10 Aug. 2016].

LORD, D. & MANNERING, F. 2010. The statistical analysis of crash-frequency data: a review and assessment of methodological alternatives. *Transportation Research Part A: Policy and Practice,* 44**,** 291-305.

LORD, D., MIDDLETON, D. & WHITACRE, J. 2005. Does separating trucks from other traffic improve overall safety? *Transportation Research Record: Journal of the Transportation Research Board***,** 156-166.

MANNERING, F. L. & BHAT, C. R. 2014. Analytic methods in accident research: methodological frontier and future directions. *Analytic methods in accident research,* 1**,** 1-22.

MANNERING, F. L., SHANKAR, V. & BHAT, C. R. 2016. Unobserved heterogeneity and the statistical analysis of highway accident data. *Analytic methods in accident research*, 11**,** 1-16.

MARTIN, J.-L. 2002. Relationship between crash rate and hourly traffic flow on interurban motorways. *Accident Analysis & Prevention,* 34**,** 619-629.

MAYCOCK, G. & HALL, R. 1984. Accidents at four-arm roundabouts.

MIAOU, S.-P. 1994. The relationship between truck accidents and geometric design of road sections: Poisson versus negative binomial regressions. *Accident Analysis & Prevention,* 26**,** 471-482.

MIAOU, S.-P. & LUM, H. 1993. Modeling vehicle accidents and highway geometric design relationships. *Accident Analysis & Prevention,* 25**,** 689-709.

MIAOU, S.-P. & LORD, D. 2003. Modeling traffic crash-flow relationships for intersections: dispersion parameter, functional form, and Bayes versus empirical Bayes methods. *Transportation Research Record: Journal of the Transportation Research Board***,** 31-40.

MICROLISE LTD. 2016. *Microlise Official Website.* Available at: http://www.microlise.com/ [Accessed 10 Aug. 2016]

MILTON, J. & MANNERING, F. 1998. The relationship among highway geometrics, traffic-related elements and motor-vehicle accident frequencies. *Transportation,* 25**,** 395-413.

MILTON, J. C., SHANKAR, V. N. & MANNERING, F. L. 2008. Highway accident severities and the mixed logit model: an exploratory empirical analysis. *Accident Analysis & Prevention,* 40**,** 260-266.

MOHAMEDSHAH, Y. M., PANIATI, J. F. & HOBEIKA, A. G. 1993. Truck accident models for interstates and two-lane rural roads. *Transportation Research Record*.

MONTELLA, A. 2007. Roundabout in-service safety reviews: safety assessment procedure. *Transportation Research Record: Journal of the Transportation Research Board,* 2019**,** 40-50.

NIEUWENHUIS, R., TE GROTENHUIS, H. & PELZER, B. 2012. Influence. ME: tools for detecting influential data in mixed effects models.

O'BRIEN, R. M. 2007. A caution regarding rules of thumb for variance inflation factors. *Quality & Quantity,* 41**,** 673-690.

OGP 2014, *Land Transportation Safety Recommended Practice*. Guidance note 12 (version 2), Available at: http://www.ogp.org.uk/pubs/365-12.pdf/ [Accessed 10 Aug. 2016].

OLSON, R., HANOWSKI, R., HICKMAN, J. & BOCANEGRA, J. 2009. Driver distraction in commercial operations vehicle. *Federal Motor Carrier Safety Administration, DC, FMCSA-RRR-09,* 42.

PEIRSON, J., SKINNER, I. & VICKERMAN, R. 1998. The microeconomic analysis of the external costs of road accidents. *Economica,* 65**,** 429-440.

PERSAUD, B. N., RETTING, R. A., GARDER, P. E. & LORD, D. 2001. Observational BeforeAfter Study of the Safety Effect of US. *In:* Transportation Research Board, National Research Council. Citeseer.

PRATO, C. G., KAPLAN, S., RASMUSSEN, T. K. & HELS, T. 2015. Infrastructure and spatial effects on the frequency of cyclist-motorist collisions in the Copenhagen Region. *Journal of Transportation Safety & Security***,** 00-00.

QIAN, S., XIA, J., NADARAJAH, N., FALKMER, T., FOSTER, J. & LEE, H. 2015. Positioning Eye Fixation and Vehicle Movement: Visual-motor Coordination Assessment in Naturalistic Driving. published at http://ceur-ws.org.

QUEST GEO SOLUTIONS LTD (2004). Grid InQuest DLL User Manual (Version 6).

RUHL LAURA L, DOOLEY-OWEN MARY K., 2012. Truck Accident Litigation, 3rd. ed. American Bar Association, KF2265.A74 T778 2012.

RETTING, R. 2006. Enhancing Intersection Safety Through Roundabouts: A Proposed ITE Informational Report. *In:* ITE 2006 Technical Conference and Exhibit Compendium of Technical Papers.

RETTING, R. A., PERSAUD, B. N., GARDER, P. E. & LORD, D. 2001. Crash and injury reduction following installation of roundabouts in the United States. *American journal of public health*, 91**,** 628.

RIGBY, D. & BURTON, M. 2003. Capturing preference heterogeneity in stated choice models: a random parameter logit model of the demand for GM food. *The University of Manchester, School of Economic Studies Discussion Paper Series*.

RODEGERDTS, L., BLOGG, M.,WEMPLE, E., MYERS, E., KYTE, M., DIXON, M., LIST, G., FLANNERY, A., TROUTBECK, R., BRILON, W., WU, N., PERSAUD, B., LYON, C., HARKEY, D., CARTER, D., 2007A. NCHRP Report 572: Roundabouts in the United States. Transportation Research Board, Washington, DC.

RODEGERDTS,L., BANSEN,J., TIESLER,C., KNUDSEN,J., MYERS, E., JOHNSON,J., MOULE, M., PERSAUD,B., LYON,C., HALLMARK,S., ISEBRANDS,H., CROWN,R., GUICHET, B., AND O'BRIEN, A., 2010. NCHRP Report 672: Roundabouts: An informational guide, Transportation Research Board, Washington, DC.

RUDIN-BROWN, C. & JAMSON, S. 2013. *Behavioural adaptation and road safety: Theory, evidence and action*, CRC Press.

SALIFU, M. 2004. Accident prediction models for unsignalised urban junctions in Ghana. *IATSS research,* 28**,** 68-81.

ŠENK, P. & AMBROS, J. 2011. Estimation of Accident Frequency at Newly-built Roundabouts in the Czech Republic. *Transactions on Transport Sciences,* 4**,** 199-206.

SHADPOUR ELA 2012. Safety Effects of Roundabouts, MA Wilfrid Laurier University, LCERPA Commentary No. 2014--2.

SILVA, A. B., SANTOS, S., VASCONCELOS, L., SECO, Á. & SILVA, J. P. 2014. Driver Behavior Characterization in Roundabout Crossings. *Transportation Research Procedia,* 3**,** 80-89.

SIMONS-MORTON, B. G., OUIMET, M. C., WANG, J., KLAUER, S. G., LEE, S. E. & DINGUS, T. A. 2009. Hard braking events among novice teenage drivers by passenger characteristics. *In:* Proceedings of the... International Driving Symposium on Human Factors in Driver Assessment, Training, and Vehicle Design.NIH Public Access, 236.

SIMONS-MORTON, B. G., OUIMET, M. C., ZHANG, Z., KLAUER, S. E., LEE, S. E., WANG, J., ALBERT, P. S. & DINGUS, T. A. 2011. Crash and risky driving involvement among novice adolescent drivers and their parents. *American journal of public health,* 101**,** 2362-2367.

STATTREK, 2016. *Stat Trek, Teach Yourself Statistics*. Available at: http://stattrek.com/ [Accessed 10 Aug. 2016].

SINGPURWALLA, D. 2016. A Handbook of Statistics.

STEVENS, J. P. 1984. Outliers and influential data points in regression analysis. Psychological Bulletin, 95, 334.

TELETRAC 2016. *Teletrac Vanman*. Available at: www.teletrac.com/ [Accessed 10 Aug. 2016].

TLSM Transport for London Street Management 2005. Do Traffic Signals at Roundabouts Save Lives? Transportation Professional.

TRAIN, K. 1999. Mixed logit models for recreation demand. *Valuing Recreation and the Environment', Edward Elgar, Northampton, MA.*

TRUCKS, V. 2013. EUROPEAN ACCIDENT RESEARCH AND SAFETY REPORT.

TURNER, D. & THOMAS, R. 1986. Motorway accidents: an examination of accident totals, rates and severity and their relationship with traffic flow. *Traffic Engineering and Control,* 27**,** 377-383.

TURNER, S., WOOD, G. & ROOZENBURG, A. 2006. Accident prediction models for roundabouts. *In:* Research into Practice: 22nd ARRB Conference.

UKKUSURI, S., HASAN, S. & AZIZ, H. 2011. Random parameter model used to explain effects of built-environment characteristics on pedestrian crash frequency. *Transportation Research Record: Journal of the Transportation Research Board***,** 98-106.

US DEPARTMENT OF TRANSPORTATION 2014."Traffic Safety Facts", National Highway Traffic Safety Administration, DOT HS 812 101, Washington, DC 20590.

VAN DER MEER, T., TE GROTENHUIS, M. & PELZER, B. 2010. Influential Cases in Multilevel Modeling A Methodological Comment. *American Sociological Review,* 75**,** 173-178.

Vehicle Valuation Services, Inc. *TRUCK, TRACTOR and TRAILER QUICK REFERENCE GUIDE. 2000.* Available at: http://docplayer.net/8373694-Truck-tractor-and-trailer.html.

VENKATARAMAN, N. S. 2014. Random parameter analysis of geometric effects on freeway crash occurrence.

WANG, C., QUDDUS, M. A. & ISON, S. G. 2009. Impact of traffic congestion on road accidents: a spatial analysis of the M25 motorway in England. *Accident Analysis & Prevention,* 41**,** 798-808.

WASHINGTON, S., KARLAFTIS, M. & MANNERING, F. 2011. Statistical and Econometric Methods for Transportation Data Analysis, Second Edition.

WEBER, M.ENG, P.ENG & NANCY BUTTON, M. 2009. Accommodating Small and Large Users at Roundabouts. *In:* Annual Conference of the Transportation Association of Canada: Sustainability in Development and Geometric Design for Roadways, Vancouver, British Columbia, Canada.

WITTY LARRY, BOYAK SARAH, AND LAW PETER, 1999, Department For Transport-Tommorow Roads Safer For Everyone, Uk Roads. Org

WORLD HEALTH ORGANIZATION, 2013. Global Status Report on Road Safety 2013: Supporting a Decade of Action. World Health Organization, Geneva, Switzerland.

List of Conferences

- **Feasibility of Using Truck Position Data to Identify Accident Risk**

The 4th International Safer Roads Conference. Cheltenham, UK, 18 - 21 May 2014.
Authors: Tony Parry, Jwan Kamla, and Ian Dickinson

- **Analysing Near-miss Incidents Using Truck Position Data on M1 Motorway Roundabouts**

Kurdistan Student Conference, hosted jointly by the Kurdistan Society and the International Office of Nottingham University, UK, 15 Sept 2014.
Authors: Jwan Kamla, and Tony Parry

- **Analysing Truck Position Data to Study Roundabout Accident Risk**

Transportation Research Board, 94th Annual Meeting, January 11-15, 2015- Washington, D.C. January 13, 2015.
Authors: Jwan Kamla, Tony Parry, and Ian Dickinson

- **Roundabout Accident Prediction Model: An Application of Random Parameters Negative Binomial Approach to Roundabout Accidents in the United Kingdom**

Transportation Research Board, 94th Annual Meeting, January 10-14, 2016- Washington, D.C. January 14, 2016.
Authors: Jwan Kamla, Tony Parry, and Ian Dickinson

Publication

- **Roundabout Accident Prediction Model: Random-Parameter Negative Binomial Approach.**

Transportation Research Record, Journal of the Transportation Research Board. DOI 10.3141/2585-02, *No. 2585*, pp. 11–19.

Authors: Jwan Kamla, Tony Parry, and Andrew Dawson

Submitted to Transportation Research Record 2017, for Presentation and Publication

- **Application Of Random Parameters Model To Estimate Truck Accidents At Roundabouts**

Authors: Jwan Kamla, Tony Parry, and Andrew Dawson

- **Feasibility Of Using Truck Harsh Braking Incidents For Predicting All Vehicle Accidents At Roundabouts**

Authors: Jwan Kamla, Andrew Dawson, and Tony Parry

Certification

Finalist in the Engineering Research Showcase for their Poster **"Feasibility of using Truck Sensor Data for Prioritizing Safety Measures "** The University of Nottingham, May 2014.

Appendix A

STATS19 Form

MG NSRF/A

ACCIDENT STATISTICS

*FATAL / SERIOUS / SLIGHT

Sept 2011

Incident URN

Other ref.

1.3 ACCIDENT REFERENCE

1.9 *TIME* H H M M

*DAY** Su M T W Th F S

1.7 *DATE* D D M M 2 0 Y Y

1st Road Class & No. or (Unclassified - UC) (Not Known - NK)

1st Road Name

Outside House No. or Name or Marker Post No.

at junction with / or *metres* N S E W * of

2nd Road Class & No. or (Unclassified - UC) (Not Known - NK)

2nd Road Name

Town

Sector /Beat No.

County or Borough

Parish No. or Name

1.10 *Local Auth No. (if known)*

1.11 *Grid Reference* E — N

REPORTING OFFICER *Name* *Number*

BCU/Stn 1.2 *Force* *Tel Number*

1.5 Number of vehicles

1.6 Number of casualties

1.14 ROAD TYPE	✗
Roundabout	1
One way street	2
Dual carriageway	3
Single carriageway	6
Slip road	7
Unknown	9

1.15 Speed Limit (Permanent)

1.16 JUNCTION DETAIL	✗
Not at or within 20 metres of junction	00
Roundabout	01
Mini roundabout	02
T or staggered junction	03
Slip road	05
Crossroads	06
Junction more than four arms (not RAB)	07
Using private drive or entrance	08
Other junction	09

JUNCTION ACCIDENTS ONLY

1.17 JUNCTION CONTROL	✗
Authorised person	1
Automatic traffic signal	2
Stop sign	3
Give way or uncontrolled	4

1.20a PEDESTRIAN CROSSING - HUMAN CONTROL	✗
None within 50 metres	0
Control by school crossing patrol	1
Control by other authorised person	2

1.20b PEDESTRIAN CROSSING - PHYSICAL FACILITIES	✗
No physical crossing facility within 50m	0
Zebra crossing	1
Pelican, puffin, toucan or similar non-junction pedestrian light crossing	4
Pedestrian phase at traffic signal junction	5
Footbridge or subway	7
Central refuge — no other controls	8

1.22 WEATHER	✗
Fine without high winds	1
Raining without high winds	2
Snowing without high winds	3
Fine with high winds	4
Raining with high winds	5
Snowing with high winds	6
Fog or mist — if hazard	7
Other	8
Unknown	9

1.23 ROAD SURFACE CONDITION	✗
Dry	1
Wet / Damp	2
Snow	3
Frost / Ice	4
Flood (surface water over 3cm deep)	5

1.21 LIGHT CONDITIONS	✗
Daylight	1
Darkness: street lights present and lit	4
Darkness: street lights present but unlit	5
Darkness: no street lighting	6
Darkness: street lighting unknown	7

1.24 SPECIAL CONDITIONS AT SITE	✗
None	0
Auto traffic signal out	1
Auto traffic signal partially defective	2
Permanent road signing or marking defective or obscured	3
Roadworks	4
Road surface defective	5
Oil or diesel	6
Mud	7

1.25 CARRIAGEWAY HAZARDS	✗
None	0
Dislodged vehicle load in carriageway	1
Other object in carriageway	2
Involvement with previous accident	3
Pedestrian in carriageway - not injured	6
Any animal in carriageway (except ridden horse)	7

1.26 Did a police officer attend the scene and obtain the details for this report?	✗
Yes	1
No	2

Subject to local directions, boxes with a grey background need not be completed if already recorded

** Circle as appropriate*

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VEHICLE RECORD

Sept 2011

2.26 VEHICLE REGISTRATION MARK

Vehicle 001	
Vehicle 002	
Vehicle 003	
Vehicle 004	

2.35 WAS THE VEHICLE LEFT HAND DRIVE ✗

		VEHICLE 1	2	3	4
No	1				
Yes	2				

2.5 / 2.5a TYPE OF VEHICLE ✗

Car	09				
Taxi / Private hire car	08				
Van - Goods vehicle 3.5 tonnes mgw and under	19				
Goods vehicle over 3.5 tonnes mgw and under 7.5 tonnes mgw	20				
Goods vehicle 7.5 tonnes mgw & over	21				
Goods vehicle - unknown weight	98				
M/cycle 50cc and under	02				
M/cycle over 50cc and up to 125cc	03				
M/cycle over 125cc and up to 500cc	04				
Motorcycle over 500cc	05				
Motorcycle - cc unknown	97				
Electric Motorcycle	23				
Pedal cycle	01				
Bus or coach (17 or more passenger seats)	11				
Minibus (8-16 passenger seats)	10				
Agricultural vehicle (include diggers etc)	17				
Ridden horse	16				
Mobility scooter	22				
Tram / Light rail	18				
Other vehicle 1	90				
2	90				
3	90				
4	90				

2.6 TOWING AND ARTICULATION ✗

No tow or articulation	0				
Articulated vehicle	1				
Double or multiple trailer	2				
Caravan	3				
Single trailer	4				
Other tow	5				

2.22 AGE OF DRIVER (Estimate if necessary)

Vehicle 001		Vehicle 002	
Vehicle 003		Vehicle 004	

2.27 DRIVER HOME POSTCODE
or Code: 1- Unknown 2- Non UK Resident 3 - Parked & unattended

Vehicle 001		
Vehicle 002		
Vehicle 003		
Vehicle 004		

2.23 BREATH TEST ✗

		VEHICLE 1	2	3	4
Not applicable	0				
Positive	1				
Negative	2				
Not requested	3				
Refused to provide	4				
Driver not contacted at time of col'	5				
Not provided (medical reasons)	6				

2.24 HIT AND RUN ✗

Not hit and run	0				
Hit and run	1				
Non-stop vehicle, not hit	2				

2.21 SEX OF DRIVER ✗

Male	1				
Female	2				
Not known	3				

2.9 VEHICLE LOCATION AT TIME OF ACCIDENT RESTRICTED LANE/AWAY FROM MAIN C'WAY ✗

On main carriageway not in restricted lane	00				
Tram / Light rail track	01				
Bus lane	02				
Busway (inc. guided busway)	03				
Cycle lane (on main carriageway)	04				
Cycleway or shared use footway (not part of main carriageway)	05				
On lay-by / hard shoulder	06				
Entering lay-by/ hard shoulder	07				
Leaving lay-by / hard shoulder	08				
Footway (pavement)	09				

2.10 JUNCTION LOCATION OF VEHICLE ✗

Not at or within 20m of junction	0				
Approaching junction or waiting /parked at junction approach	1				
Cleared junction or waiting / parked at junction exit	2				
Leaving roundabout	3				
Entering roundabout	4				
Leaving main road	5				
Entering main road	6				
Entering from slip road	7				
Mid junction– on roundabout or on main road	8				

2.7 MANOEUVRES ✗

Reversing	01				
Parked	02				
Waiting to go ahead but held up	03				
Slowing or stopping	04				
Moving off	05				
U turn	06				
Turning left	07				
Waiting to turn left	08				
Turning right	09				
Waiting to turn right	10				
Changing lane to left	11				
Changing lane to right	12				
O'taking moving veh on its offside	13				
O'taking stationary veh on its offside	14				
Overtaking on nearside	15				
Going ahead left hand bend	16				
Going ahead right hand bend	17				
Going ahead other	18				

2.11 SKIDDING AND OVERTURNING ✗

		VEHICLE 1	2	3	4
No skidding, jack-knifing or overturning	0				
Skidded	1				
Skidded and overturned	2				
Jack - knifed	3				
Jack - knifed and overturned	4				
Overturned	5				

2.12 HIT OBJECT IN CARRIAGEWAY ✗

None	00				
Previous accident	01				
Roadworks	02				
Parked vehicle	04				
Bridge - roof	05				
Bridge - side	06				
Bollard / Refuge	07				
Open door of vehicle	08				
Central island of roundabout	09				
Kerb	10				
Any animal (except ridden horse)	12				
Other object	11				

2.13 VEHICLE LEAVING CARRIAGEWAY ✗

Did not leave carriageway	0				
Left carriageway nearside	1				
Left carriageway nearside and rebounded	2				
Left carriageway straight ahead at junction	3				
Left carriageway offside onto central reservation	4				
Left carriageway offside onto central reserve and rebounded	5				
Left carriageway offside and crossed central reservation	6				
Left carriageway offside	7				
Left carriageway offside and rebounded	8				

2.14 FIRST OBJECT HIT OFF CARRIAGEWAY ✗

None	00				
Road sign / Traffic signal	01				
Lamp post	02				
Telegraph pole / Electricity pole	03				
Tree	04				
Bus stop / Bus shelter	05				
Central crash barrier	06				
Nearside or offside crash barrier	07				
Submerged in water (completely)	08				
Entered ditch	09				
Wall or fence	11				
Other permanent object	10				

2.16 FIRST POINT OF IMPACT ✗

Did not impact	0				
Front	1				
Back	2				
Offside	3				
Nearside	4				

2.29 JOURNEY PURPOSE OF DRIVER/RIDER ✗

Journey as part of work	1				
Commuting to / from work	2				
Taking school pupil to/from school	3				
Pupil riding to / from school	4				
Other	5				
Not known	6				

Subject to local directions, boxes with a grey background need not be completed if already recorded

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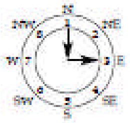
2.8 DIRECTION OF VEHICLE TRAVEL

1. Using the Example shown complete the FROM and TO boxes for the vehicles concerned, indicating direction of travel FROM and TO
2. If PARKED enter '00'

	FROM	TO
Vehicle 001		
Vehicle 002		
Vehicle 003		
Vehicle 004		

EXAMPLE

FROM	TO
1	3



CASUALTY RECORD

3.4 VEHICLE REFERENCE NUMBER
Enter VEH No. which CASUALTY occupied (for pedestrians, code vehicle that struck them first) e.g. 001,002 etc.

Casualty 001	0	Casualty 002	0
Casualty 003	0	Casualty 004	0
Casualty 005	0	Casualty 006	0

3.18 CASUALTY HOME POSTCODE
or Code: 1- Unknown
2- Non UK Resident

Casualty 001		
Casualty 002		
Casualty 003		
Casualty 004		
Casualty 005		
Casualty 006		

3.7 SEX OF CASUALTY ✗

		CASUALTY 1	2	3	4	5	6
Male	1						
Female	2						

3.8 AGE OF CASUALTY (Estimate if necessary)
For children less than a year enter 00

Casualty 001		Casualty 002	
Casualty 003		Casualty 004	
Casualty 005		Casualty 006	

3.6 CASUALTY CLASS ✗

		1	2	3	4	5	6
Driver/Rider	1						
Veh./pillion Passenger	2						
Pedestrian	3						

3.9 SEVERITY OF CASUALTY ✗

		1	2	3	4	5	6
Fatal	1						
Serious	2						
Slight	3						

3.20 CYCLE HELMET WORN ✗

		CASUALTY 1	2	3	4	5	6
Not a cyclist	0						
Yes	1						
No	2						
Not known	3						

3.15 CAR PASSENGER (not driver) ✗

		1	2	3	4	5	6
Not a car passenger	0						
Front seat passenger	1						
Rear seat passenger	2						

3.16 BUS OR COACH PASSENGER ✗
(17 passenger seats or more)

		1	2	3	4	5	6
Not a bus or coach passenger	0						
Boarding	1						
Alighting	2						
Standing passenger	3						
Seated passenger	4						

LOCAL STATISTICS

3.14 SEAT BELT IN USE ✗

		1	2	3	4	5	6
Not applicable	0						
Worn and independently confirmed	1						
Worn but not independently confirmed	2						
Not worn	3						
Unknown	4						

PEDESTRIAN CASUALTIES ONLY

3.10 PEDESTRIAN LOCATION ✗

		CASUALTY 1	2	3	4	5	6
In carriageway, crossing on pedestrian crossing facility	01						
In carriageway, crossing within zig-zag lines at crossing approach	02						
In carriageway, crossing within zig-zag lines at crossing exit	03						
In carriageway, crossing elsewhere within 50m of pedestrian crossing	04						
In carriageway, crossing elsewhere	05						
On footway or verge	06						
On refuge, central island or central reservation	07						
In centre of carriageway, not on refuge, island or central reservation	08						
In carriageway, not crossing	09						
Unknown or other	10						

3.12 PEDESTRIAN DIRECTION ✗

		CASUALTY 1	2	3	4	5	6
Standing still	0						
Northbound	1						
Northeast bound	2						
Eastbound	3						
Southeast bound	4						
Southbound	5						
Southwest bound	6						
Westbound	7						
Northwest bound	8						
Unknown	9						

3.19 PEDESTRIAN ROAD MAINTENANCE WORKER ✗

		1	2	3	4	5	6
No / not applicable	0						
Yes	1						
Not known	2						

3.11 PEDESTRIAN MOVEMENT ✗

		CASUALTY 1	2	3	4	5	6
Crossing from driver's nearside	1						
Crossing from driver's nearside-masked by parked or stationary veh'	2						
Crossing from driver's offside	3						
Crossing from driver's offside-masked by parked or stationary veh'	4						
In carriageway, stationary - not crossing (standing or playing)	5						
In carriageway, stationary -not crossing (standing or playing), masked by parked or stationary veh'	6						
Walking along in carriageway-facing traffic	7						
Walking along in carriageway-back to traffic	8						
Unknown or other	9						

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CONTRIBUTORY FACTORS

1. Select up to six factors from the grid, relevant to the accident.
2. Factors may be shown in any order, but an indication must be given of whether each factor is *very likely (A)* or *possible (B)*.
3. Only include factors that you consider contributed to the accident. (i.e. do NOT include "Poor road surface" unless relevant).
4. More than one factor may, if appropriate, be related to the same road user.
5. The same factor may be related to more than one road user.
6. The participant should be identified by the relevant vehicle or casualty ref no. (e.g. 001, 002 etc.), preceded by "V" if the factor applies to a vehicle, driver/rider or the road environment (e.g. V002), or "C" if the factor relates to a pedestrian or passenger casualty (e.g. C001).
7. Enter U000 if the factor relates to an uninjured pedestrian.

Driver/Rider Only (includes Pedal Cycles and Horse Riders) — applies to Injudicious Action, Driver/Rider Error or Reaction, Impairment or Distraction, Behaviour or Inexperience

Road Environment Contributed	**103**	**102**	**101**	**110**	**108**	**107**	**109**	**104**	**105**	**106**
	Slippery road (due to weather)	Deposit on road (e.g. oil, mud, chippings)	Poor or defective road surface	Sunken, raised or slippery inspection cover	Road layout (e.g. bend, hill, narrow carriageway)	Temporary road layout (e.g. contraflow)	Animal or object in carriageway	Inadequate or masked signs or road markings	Defective traffic signals	Traffic calming (e.g. speed cushions, road humps, chicanes)
Vehicle Defects	**201**	**202**	**203**	**204**	**205**	**206**				
	Tyres illegal, defective or under-inflated	Defective lights or indicators	Defective brakes	Defective steering or suspension	Defective or missing mirrors	Overloaded or poorly loaded vehicle or trailer				
Injudicious Action	**308**	**306**	**302**	**301**	**307**	**310**	**305**	**304**	**309**	**303**
	Following too close	Exceeding speed limit	Disobeyed Give Way or Stop sign or markings	Disobeyed automatic traffic signal	Travelling too fast for conditions	Cyclist entering road from pavement	Illegal turn or direction of travel	Disobeyed pedestrian crossing facility	Vehicle travelling along pavement	Disobeyed double white lines
Driver/ Rider Error or Reaction	**405**	**406**	**403**	**408**	**409**	**401**	**402**	**404**	**407**	**410**
	Failed to look properly	Failed to judge other person's path or speed	Poor turn or manoeuvre	Sudden braking	Swerved	Junction overshoot	Junction restart (moving off at junction)	Failed to signal or misleading signal	Too close to cyclist, horse or pedestrian	Loss of control
Impairment or Distraction	**501**	**502**	**508**	**503**	**509**	**510**	**505**	**504**	**507**	**506**
	Impaired by alcohol	Impaired by drugs (illicit or medicinal)	Driver using mobile phone	Fatigue	Distraction in vehicle	Distraction outside vehicle	Illness or disability, mental or physical	Uncorrected, defective eyesight	Rider wearing dark clothing	Not displaying lights at night or in poor visibility
Behaviour or Inexperience	**602**	**605**	**601**	**603**	**607**	**606**	**604**			
	Careless, reckless or in a hurry	Learner or inexperienced driver/rider	Aggressive driving	Nervous, uncertain or panic	Unfamiliar with model of vehicle	Inexperience of driving on the left	Driving too slow for conditions or slow vehicle (e.g. tractor)			
Vision Affected by	**701**	**703**	**706**	**707**	**708**	**705**	**710**	**702**	**704**	**709**
	Stationary or parked vehicle(s)	Road layout (e.g. bend, winding road, hill crest)	Dazzling sun	Rain, sleet, snow or fog	Spray from other vehicles	Dazzling headlights	Vehicle blind spot	Vegetation	Buildings, road signs, street furniture	Visor or windscreen dirty, scratched or frosted etc.
Pedestrian Only (Casualty or Uninjured)	**802**	**808**	**803**	**801**	**806**	**807**	**805**	**804**	**809**	**810**
	Failed to look properly	Careless, reckless or in a hurry	Failed to judge vehicle's path or speed	Crossing road masked by stationary or parked vehicle	Impaired by alcohol	Impaired by drugs (illicit or medicinal)	Dangerous action in carriageway (e.g. playing)	Wrong use of pedestrian crossing facility	Pedestrian wearing dark clothing at night	Disability or illness, mental or physical
Special Codes	**901**	**902**	**903**	**904**						***999**
	Stolen vehicle	Vehicle in course of crime	Emergency vehicle on a call	Vehicle door opened or closed negligently						Other – Please specify below

	1st	*2nd*	*3rd*	*4th*	*5th*	*6th*
Factor in the accident						
Which participant? (e.g. V001, C001, U000)						
Very likely (A) or Possible (B)						

*If 999 Other, give brief details

(Note: Only use if another factor contributed to the accident *and include it in the text description of how the accident occurred*)

These factors reflect the reporting officer's opinion at the time of reporting and may not be the result of extensive investigation

Appendix B

On site Measured Distance Locations (Hassocks Lane)

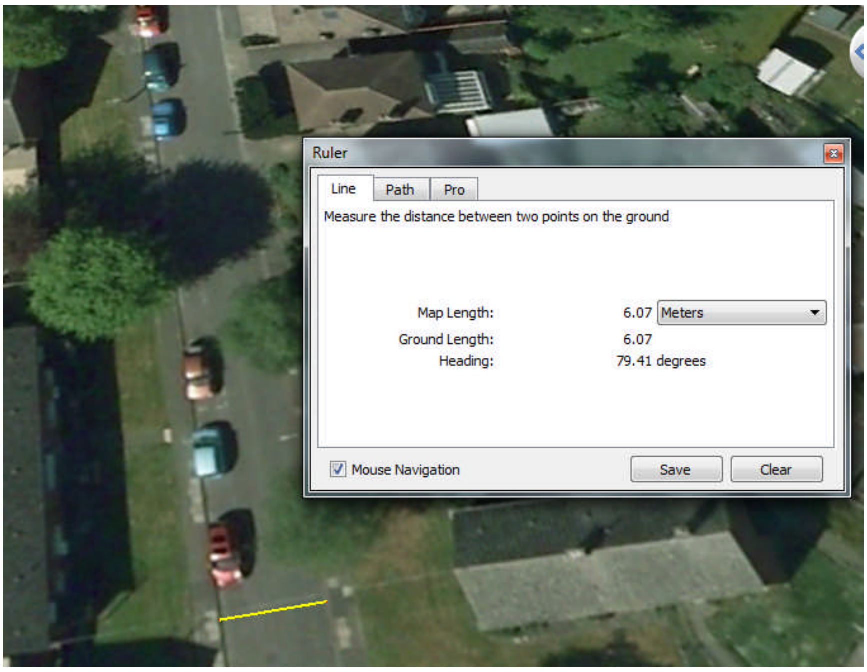


Figure B-1 Tattershall Drive road (Original distance is 6.11m)

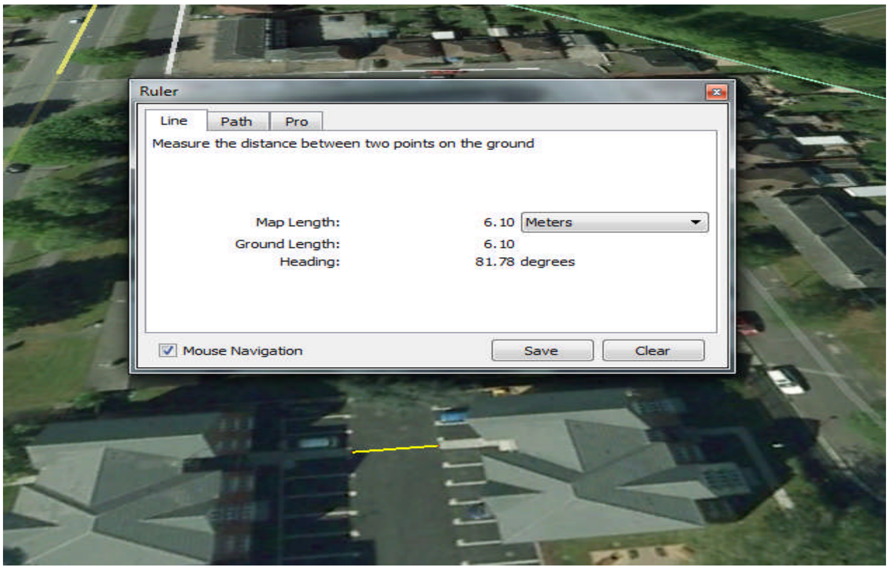


Figure B-2 Hassocks Close Garage (Original distance is 6.12m)

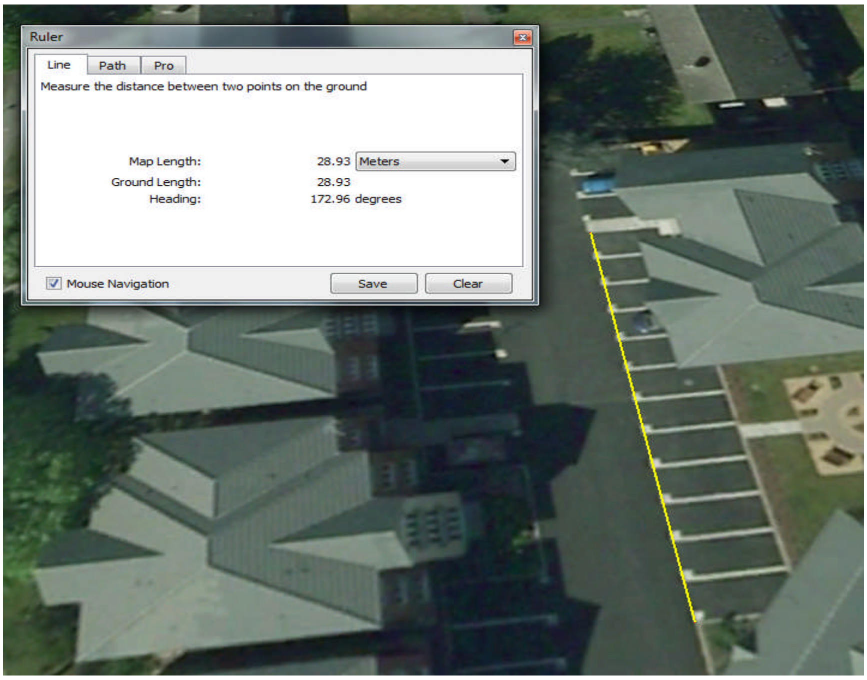


Figure B-3 Hassocks Close Garage (Original distance is 28.91m)

Appendix C

Traffic Volume MATLAB Program

```
function [esum]=MinErrTr2(OD)

% Link volumes
% a, c, e and g are inflows
% b, d, f and h are outflows
(a=6484; b=6069; c=9142; d=8954; e=12135; f=12193; g=8954; h=9142;)[1]

%prior matrix
%probability of destination given some origin = probability of destination
ad=d/(d+f+h); af=f/(d+f+h); ah=h/(d+f+h);
cb=b/(b+f+h); cf=f/(b+f+h); ch=h/(b+f+h);
eb=b/(b+d+h); ed=d/(b+d+h); eh=h/(b+d+h);
gb=b/(b+d+f); gd=d/(b+d+f); gf=f/(b+d+f);

% Prior matrix = probability(destination)*volume(origin)
% Note that outflows are constrained to some inflows
pmat=[0 ad*a af*a ah*a; cb*c 0 cf*c ch*c;...
    eb*e ed*e 0 eh*e; gb*g gd*g gf*g 0];

% Develop the origin destination matrix with the inputs from the
% minimisation function
x=zeros(4);
x(1,1)=0; x(1,2)=OD(1); x(1,3)=OD(2); x(1,4)=OD(3);
x(2,1)=OD(4); x(2,2)=0; x(2,3)=OD(5); x(2,4)=OD(6);
x(3,1)=OD(7); x(3,2)=OD(8); x(3,3)=0; x(3,4)=OD(9);
x(4,1)=OD(10); x(4,2)=OD(11); x(4,3)=OD(12); x(4,4)=0;

%sum the rows and columns for flows
A1=(sum(x(1,:))[2]-a[3])^2;
B1=(sum(x(:,1))-b)^2;
C1=(sum(x(2,:))-c)^2;
D1=(sum(x(:,2))-d)^2;
E1=(sum(x(3,:))-e)^2;
F1=(sum(x(:,3))-f)^2;
G1=(sum(x(4,:))-g)^2;
H1=(sum(x(:,4))-h)^2;

% minimise esum
esum1=A1+B1+C1+D1+E1+F1+G1+H1;

esum=sum(sum((x-pmat).^2))+esum1;
```

[1] An example of the traffic data of this study
[2] Computed value
[3] Original value

Origin/Destination Matrix

```
% This code runs a minimisation algorithm to assign values to an OD[4] matrix
% The number of simulations (i) is up to the user, but should be chosen as
% large enough to determine if the solution is stable
[5]for i=1:50
    % Time the simulations
    tic[6]

    % Set the parameters for the minimisations
    IntCon[7] = 1:12; % integer constraint
    lb[8]=100.*ones(12,1)[9]; %sets minimum value as 100 vehicles per OD pair
    ub[10]=100000.*ones(12,1); %sets max value as 100000 vehicles per OD pair
    opts[11] = gaoptimset[12]('PlotFcns',@gaplotbestf[13], 'TolFun'[14], 1e-8[15]);

    % Min function using genetic algorithm
    % This calls (and minimises) the function MinErrTr2
    [x,fval1[16]] = ga(@MinErrTr2,12,[],[],[],[],...
        lb,ub,[],IntCon,opts);

    % populate the origin destination matrix for each run
    mat2(1,1,i)=0; mat2(1,2,i)=x(1); mat2(1,3,i)=x(2); mat2(1,4,i)=x(3);
    mat2(2,1,i)=x(4); mat2(2,2,i)=0; mat2(2,3,i)=x(5); mat2(2,4,i)=x(6);
    mat2(3,1,i)=x(7); mat2(3,2,i)=x(8); mat2(3,3,i)=0; mat2(3,4,i)=x(9);
    mat2(4,1,i)=x(10); mat2(4,2,i)=x(11); mat2(4,3,i)=x(12); mat2(4,4,i)=0;

    % store the error term from the ga function
    termErr(i)=fval1;

    toc[17]
end

% This populates 5, 50 and 95 percent values for the OD matrix
for i=1:4
    for j=1:4
        mat5(i,j)=quantile(mat2(i,j,:),0.05);
        mat50(i,j)=prctile(mat2(i,j,:),0.50);
        mat95(i,j)=quantile(mat2(i,j,:),0.95);

    end
end
```

[4] OD is the origin/destination
[5] The functions illustrated within this bracelet draw and run genetic algorithm for 50 times.
[6] Tic is the time (start stopwatch timer)
[7] IntCon is a vector of positive integers that contains the x components that are integer-valued, for instance to restrict x(2) and x(10) as an integer, set IntCon to (2,10).
[8] Lower bound
[9] Ones (12,1) create 12 by 1 matrix of ones
[10] Upper bound
[11] Options (options are set using the optimist function, they determine what algorithm to use)
[12] Generation
[13] Best fitness (plots the best function value against generation)
[14] Function tolerance (termination tolerance for the objective function, and it is set to 1e-8 (i.e, 1 * 10^{-8}))
[15] Ie-8 is used for integer constrained problem
[16] Fval1 is the optimal value of the objective function, which is the penalty
[17] Elapsed time in seconds (reads the elapsed time from the stopwatch timer by the tic function)
(source: Matlab, 2016)

Appendix D

Selected Roundabouts with Accidents, Harsh Braking Incidents, Traffic and Geometric Variables

J23 on the M1

Total traffic AADT (sum of entry traffic)	48095
Truck %	5.8
Inscribed circle diameter (m)	182
Circulatory roadway width (m)	7.8
Average entry width (m)	8.1
Number of lanes	2
Type of signalisation	Partially signalised
Type of grade	Grade-separated
Total accident (entry +circulatory lanes)	26
Truck accident (entry +circulatory lanes)	7
Harsh braking incident (entry +circulatory lanes)	37

J26 on the M1

Total traffic AADT (sum of entry traffic)	89880
Truck %	6.2
Inscribed circle diameter (m)	179
Circulatory roadway width (m)	13.5
Average entry width (m)	10.6
Number of lanes	3
Type of signalisation	Partially signalised
Type of grade	Grade-separated
Total accident (entry +circulatory lanes)	32
Truck accident (entry +circulatory lanes)	9
Harsh braking incident (entry +circulatory lanes)	96

J27 on the M1

Total traffic AADT (sum of entry traffic)	36522
Truck %	5.2
Inscribed circle diameter (m)	211
Circulatory roadway width (m)	9
Average entry width (m)	8.7
Number of lanes	2
Type of signalisation	Un-signalised
Type of grade	Grade-separated
Total accident (entry +circulatory lanes)	15
Truck accident (entry +circulatory lanes)	4
Harsh braking incident (entry +circulatory lanes)	41

Total traffic AADT (sum of entry traffic)	106959
Truck %	9.6
Inscribed circle diameter (m)	231
Circulatory roadway width (m)	12.5
Average entry width (m)	12.1
Number of lanes	3
Type of signalisation	Signalised
Type of grade	Grade-separated
Total accident (entry + circulatory lanes)	138
Truck accident (entry + circulatory lanes)	728
Harsh braking incident (entry +circulatory lanes)	28

J28 on the M1

Total traffic AADT (sum of entry traffic)	52356
Truck %	7.4
Inscribed circle diameter (m)	280
Circulatory roadway width (m)	13.0
Average entry width (m)	8.5
Number of lanes	Partially signalised
Type of signalisation	2
Type of grade	Grade-separated
Total accident (entry + circulatory lanes)	152
Truck accident (entry + circulatory lanes)	54
Harsh braking incident (entry +circulatory lanes)	35

J29 on the M1

Total traffic AADT (sum of entry traffic)	38179
Truck %	6.1
Inscribed circle diameter (m)	170
Circulatory roadway width (m)	9.4
Average entry width (m)	7.5
Number of lanes	2
Type of signalisation	Un-signalised
Type of grade	Grade-separated
Total accident (entry + circulatory lanes)	55
Truck accident (entry + circulatory lanes)	21
Harsh braking incident (entry +circulatory lanes)	39

J30 on the M1

J33 on the M1

Total traffic AADT (sum of entry traffic)	82683
Truck %	4.6
Inscribed circle diameter (m)	195
Circulatory roadway width (m)	10.4
Average entry width (m)	8.8
Number of lanes	3
Type of signalisation	Signalised
Type of grade	Grade-separated
Total accident (entry +circulatory lanes)	85
Truck accident (entry +circulatory lanes)	26
Harsh braking incident (entry +circulatory lanes)	110

J2 on the M40

Total traffic AADT (sum of entry traffic)	13087
Truck %	7.4
Inscribed circle diameter (m)	224
Circulatory roadway width (m)	11.7
Average entry width (m)	14.1
Number of lanes	3
Type of signalisation	Signalised
Type of grade	Grade-separated
Total accident (entry +circulatory lanes)	120
Truck accident (entry +circulatory lanes)	14
Harsh braking incident (entry +circulatory lanes)	14

J15 on the M40

Total traffic AADT (sum of entry traffic)	82511
Truck %	8.1
Inscribed circle diameter (m)	262
Circulatory roadway width (m)	12.0
Average entry width (m)	11.8
Number of lanes	2
Type of signalisation	Partially signalised
Type of grade	Grade-separated
Total accident (entry +circulatory lanes)	78
Truck accident (entry +circulatory lanes)	23
Harsh braking incident (entry +circulatory lanes)	330

J2 on the M42

Total traffic AADT (sum of entry traffic)	41350
Truck %	4
Inscribed circle diameter (m)	154
Circulatory roadway width (m)	11.0
Average entry width (m)	10.7
Number of lanes	3 (circulatory lanes is 2)
Type of signalisation	Partially signalised
Type of grade	Grade-separated
Total accident (entry +circulatory lanes)	32
Truck accident (entry+circulatory lanes)	8
Harsh braking incident (entry +circulatory lanes)	84

J5 on the M42

Total traffic AADT (sum of entry traffic)	50063
Truck %	2.2
Inscribed circle diameter (m)	179
Circulatory roadway width (m)	10.5
Average entry width (m)	11.2
Number of lanes	3 (circulatory lanes is 2)
Type of signalisation	Partially signalised
Type of grade	Grade-separated
Total accident (entry +circulatory lanes)	63
Truck accident (entry+circulatory lanes)	12
Harsh braking incident (entry +circulatory lanes)	42

J11 on the M42

Total traffic AADT (sum of entry traffic)	63509
Truck %	4
Inscribed circle diameter (m)	189
Circulatory roadway width (m)	8.0
Average entry width (m)	8.4
Number of lanes	3 (circulatory lanes is 2)
Type of signalisation	Un-signalised
Type of grade	Grade-separated
Total accident (entry +circulatory lanes)	26
Truck accident (entry+circulatory lanes)	6
Harsh braking incident (entry +circulatory lanes)	4

J1 on the M54

Total traffic AADT (sum of entry traffic)	43114
Truck %	7.9
Inscribed circle diameter (m)	203
Circulatory roadway width (m)	9.0
Average entry width (m)	9.9
Number of lanes	2
Type of signalisation	Un-signalised
Type of grade	Grade-separated
Total accident (entry +circulatory lanes)	60
Truck accident (entry +circulatory lanes)	9
Harsh braking incident (entry +circulatory lanes)	138

J6 on the M54

Total traffic AADT (sum of entry traffic)	44302
Truck %	2.9
Inscribed circle diameter (m)	260
Circulatory roadway width (m)	9.0
Average entry width (m)	12.3
Number of lanes	2
Type of signalisation	Partially signalised
Type of grade	Grade-separated
Total accident (entry +circulatory lanes)	84
Truck accident (entry +circulatory lanes)	8
Harsh braking incident (entry +circulatory lanes)	62

J2 on the M6

Total traffic AADT (sum of entry traffic)	137773
Truck %	3.7
Inscribed circle diameter (m)	228
Circulatory roadway width (m)	10.0
Average entry width (m)	11.5
Number of lanes	3
Type of signalisation	Partially signalised (circulatory lanes is fully signalised)
Type of grade	Grade-separated
Total accident (entry +circulatory lanes)	155
Truck accident (entry +circulatory lanes)	33
Harsh braking incident (entry +circulatory lanes)	717

Total traffic AADT (sum of entry traffic)	53807
Truck %	6.3
Inscribed circle diameter (m)	161
Circulatory roadway width (m)	13.0
Average entry width (m)	11.2
Number of lanes	3
Type of signalisation	signalised
Type of grade	Grade-separated
Total accident (entry +circulatory lanes)	84
Truck accident (entry +circulatory lanes)	26
Harsh braking incident (entry +circulatory lanes)	54

J9 on the M6

Total traffic AADT (sum of entry traffic)	86362
Truck %	8.3
Inscribed circle diameter (m)	197
Circulatory roadway width (m)	12.0
Average entry width (m)	9.6
Number of lanes	2
Type of signalisation	signalised
Type of grade	Grade-separated
Total accident (entry +circulatory lanes)	101
Truck accident (entry +circulatory lanes)	43
Harsh braking incident (entry +circulatory lanes)	87

J10 on the M6

Total traffic AADT (sum of entry traffic)	76847
Truck %	8.9
Inscribed circle diameter (m)	223
Circulatory roadway width (m)	13.3
Average entry width (m)	11.9
Number of lanes	2
Type of signalisation	Partially signalised
Type of grade	Grade-separated
Total accident (entry +circulatory lanes)	128
Truck accident (entry +circulatory lanes)	31
Harsh braking incident (entry +circulatory lanes)	309

J11 on the M6

J12 on the M6

Total traffic AADT (sum of entry traffic)	40195
Truck %	9.4
Inscribed circle diameter (m)	185
Circulatory roadway width (m)	10.3
Average entry width (m)	9.1
Number of lanes	2
Type of signalisation	Un-signalised
Type of grade	Grade-separated
Total accident (entry +circulatory lanes)	40
Truck accident (entry +circulatory lanes)	7
Harsh braking incident (entry +circulatory lanes)	117

J13 on the M6

Total traffic AADT (sum of entry traffic)	31511
Truck %	4.8
Inscribed circle diameter (m)	181
Circulatory roadway width (m)	9.0
Average entry width (m)	7.5
Number of lanes	2
Type of signalisation	Un-signalised
Type of grade	Grade-separated
Total accident (entry +circulatory lanes)	17
Truck accident (entry +circulatory lanes)	3
Harsh braking incident (entry +circulatory lanes)	7

J16 on the M6

Total traffic AADT (sum of entry traffic)	73094
Truck %	10.4
Inscribed circle diameter (m)	174
Circulatory roadway width (m)	11.0
Average entry width (m)	9.3
Number of lanes	3
Type of signalisation	Partially signalised
Type of grade	Grade-separated
Total accident (entry +circulatory lanes)	124
Truck accident (entry +circulatory lanes)	39
Harsh braking incident (entry +circulatory lanes)	103

J19 on the M6

Total traffic AADT (sum of entry traffic)	68846
Truck %	8.5
Inscribed circle diameter (m)	206
Circulatory roadway width (m)	10.5
Average entry width (m)	13.1
Number of lanes	3
Type of signalisation	Partially signalised
Type of grade	Grade-separated
Total accident (entry +circulatory lanes)	90
Truck accident (entry +circulatory lanes)	32
Harsh braking incident (entry +circulatory lanes)	164

J23 on the M6

Total traffic AADT (sum of entry traffic)	96877
Truck %	7.8
Inscribed circle diameter (m)	171
Circulatory roadway width (m)	11.6
Average entry width (m)	10.6
Number of lanes	3
Type of signalisation	Signalised
Type of grade	Grade-separated
Total accident (entry +circulatory lanes)	140
Truck accident (entry +circulatory lanes)	24
Harsh braking incident (entry +circulatory lanes)	57

J40 on the M6

Total traffic AADT (sum of entry traffic)	55947
Truck %	9.7
Inscribed circle diameter (m)	223
Circulatory roadway width (m)	13.4
Average entry width (m)	14.7
Number of lanes	2 (circulatory lanes is 3)
Type of signalisation	Signalised
Type of grade	Grade-separated
Total accident (entry +circulatory lanes)	64
Truck accident (entry +circulatory lanes)	28
Harsh braking incident (entry +circulatory lanes)	88

Total traffic AADT (sum of entry traffic)	43976
Truck %	9.8
Inscribed circle diameter (m)	124
Circulatory roadway width (m)	12.7
Average entry width (m)	8.5
Number of lanes	3
Type of signalisation	Signalised
Type of grade	Grade-separated
Total accident (entry +circulatory lanes)	29
Truck accident (entry +circulatory lanes)	13
Harsh braking incident (entry +circulatory lanes)	58

J2 on the M5

Total traffic AADT (sum of entry traffic)	56349
Truck %	4.37
Inscribed circle diameter (m)	202
Circulatory roadway width (m)	11.5
Average entry width (m)	11.6
Number of lanes	3
Type of signalisation	Partially signalised
Type of grade	Grade-separated
Total accident (entry +circulatory lanes)	30
Truck accident (entry +circulatory lanes)	6
Harsh braking incident (entry +circulatory lanes)	55

J3 on the M5

Total traffic AADT (sum of entry traffic)	56989
Truck %	5.8
Inscribed circle diameter (m)	134
Circulatory roadway width (m)	10.6
Average entry width (m)	10.6
Number of lanes	3
Type of signalisation	Signalised
Type of grade	Grade-separated
Total accident (entry +circulatory lanes)	32
Truck accident (entry +circulatory lanes)	11
Harsh braking incident (entry +circulatory lanes)	72

J4 on the M5

J19 on the M5

Total traffic AADT (sum of entry traffic)	58888
Truck %	2.2
Inscribed circle diameter (m)	238
Circulatory roadway width (m)	12.5
Average entry width (m)	10.1
Number of lanes	3
Type of signalisation	Partially signalised
Type of grade	Grade-separated
Total accident (entry +circulatory lanes)	62
Truck accident (entry +circulatory lanes)	16
Harsh braking incident (entry +circulatory lanes)	157

J21 on the M5

Total traffic AADT (sum of entry traffic)	47209
Truck %	3.9
Inscribed circle diameter (m)	184
Circulatory roadway width (m)	9.0
Average entry width (m)	8.4
Number of lanes	2
Type of signalisation	Partially signalised
Type of grade	Grade-separated
Total accident (entry +circulatory lanes)	94
Truck accident (entry +circulatory lanes)	17
Harsh braking incident (entry +circulatory lanes)	93

J27 on the M5

Total traffic AADT (sum of entry traffic)	32040
Truck %	7.1
Inscribed circle diameter (m)	184
Circulatory roadway width (m)	7.5
Average entry width (m)	9.8
Number of lanes	2
Type of signalisation	Partially signalised
Type of grade	Grade-separated
Total accident (entry +circulatory lanes)	92
Truck accident (entry +circulatory lanes)	28
Harsh braking incident (entry +circulatory lanes)	15

Total traffic AADT (sum of entry traffic)	101143
Truck %	2.5
Inscribed circle diameter (m)	169
Circulatory roadway width (m)	12.5
Average entry width (m)	12.9
Number of lanes	3
Type of signalisation	Signalised
Type of grade	Grade-separated
Total accident (entry +circulatory lanes)	73
Truck accident (entry +circulatory lanes)	11
Harsh braking incident (entry +circulatory lanes)	59

J6 on the M4

Total traffic AADT (sum of entry traffic)	105441
Truck %	3.3
Inscribed circle diameter (m)	209
Circulatory roadway width (m)	11.5
Average entry width (m)	13.1
Number of lanes	3
Type of signalisation	Signalised
Type of grade	Grade-separated
Total accident (entry +circulatory lanes)	82
Truck accident (entry +circulatory lanes)	12
Harsh braking incident (entry +circulatory lanes)	80

J11 on the M4

Total traffic AADT (sum of entry traffic)	114387
Truck %	9.6
Inscribed circle diameter (m)	202
Circulatory roadway width (m)	12.8
Average entry width (m)	14.7
Number of lanes	3
Type of signalisation	Signalised
Type of grade	Grade-separated
Total accident (entry +circulatory lanes)	59
Truck accident (entry +circulatory lanes)	14
Harsh braking incident (entry +circulatory lanes)	240

J13 on the M4

J14 on the M4

Total traffic AADT (sum of entry traffic)	17332
Truck %	6.7
Inscribed circle diameter (m)	185
Circulatory roadway width (m)	8.7
Average entry width (m)	7.6
Number of lanes	2
Type of signalisation	Un-signalised
Type of grade	Grade-separated
Total accident (entry +circulatory lanes)	14
Truck accident (entry +circulatory lanes)	1
Harsh braking incident (entry +circulatory lanes)	8

J15 on the M4

Total traffic AADT (sum of entry traffic)	36246
Truck %	5.1
Inscribed circle diameter (m)	198
Circulatory roadway width (m)	10.0
Average entry width (m)	11.2
Number of lanes	3
Type of signalisation	Partially signalised
Type of grade	Grade-separated
Total accident (entry +circulatory lanes)	99
Truck accident (entry +circulatory lanes)	23
Harsh braking incident (entry +circulatory lanes)	158

J16 on the M4

Total traffic AADT (sum of entry traffic)	62087
Truck %	3.7
Inscribed circle diameter (m)	239
Circulatory roadway width (m)	10.4
Average entry width (m)	13.0
Number of lanes	3
Type of signalisation	Signalised
Type of grade	Grade-separated
Total accident (entry +circulatory lanes)	55
Truck accident (entry +circulatory lanes)	14
Harsh braking incident (entry +circulatory lanes)	764

J17 on the M4

Total traffic AADT (sum of entry traffic)	70940
Truck %	4
Inscribed circle diameter (m)	240
Circulatory roadway width (m)	9.7
Average entry width (m)	7.6
Number of lanes	2
Type of signalisation	Un-signalised
Type of grade	Grade-separated
Total accident (entry +circulatory lanes)	103
Truck accident (entry +circulatory lanes)	17
Harsh braking incident (entry +circulatory lanes)	152

J18 on the M4

Total traffic AADT (sum of entry traffic)	42760
Truck %	5.6
Inscribed circle diameter (m)	190
Circulatory roadway width (m)	10.6
Average entry width (m)	9.6
Number of lanes	2 (circulatory lanes is 3)
Type of signalisation	Signalised
Type of grade	Grade-separated
Total accident (entry +circulatory lanes)	38
Truck accident (entry +circulatory lanes)	5
Harsh braking incident (entry +circulatory lanes)	343

J23 on the M4

Total traffic AADT (sum of entry traffic)	63647
Truck %	4.5
Inscribed circle diameter (m)	169
Circulatory roadway width (m)	10.8
Average entry width (m)	9.4
Number of lanes	2
Type of signalisation	Un-signalised
Type of grade	Grade-separated
Total accident (entry +circulatory lanes)	22
Truck accident (entry +circulatory lanes)	3
Harsh braking incident (entry +circulatory lanes)	53

Bromley Heath roundabout

Total traffic AADT (sum of entry traffic)	48652
Truck %	5
Inscribed circle diameter (m)	71
Circulatory roadway width (m)	8.2
Average entry width (m)	10.2
Number of lanes	3
Type of signalisation	Signalised
Type of grade	Grade-separated
Total accident (entry +circulatory lanes)	37
Truck accident (entry +circulatory lanes)	2
Harsh braking incident (entry +circulatory lanes)	291

Mytton Oak Road

Total traffic AADT (sum of entry traffic)	29483
Truck %	7.3
Inscribed circle diameter (m)	70
Circulatory roadway width (m)	9.7
Average entry width (m)	8.4
Number of lanes	2
Type of signalisation	Un-signalised
Type of grade	At-grade
Total accident (entry +circulatory lanes)	12
Truck accident (entry +circulatory lanes)	2
Harsh braking incident (entry +circulatory lanes)	167

Lodge Ln, A460/Saredon Rd

Total traffic AADT (sum of entry traffic)	23094
Truck %	10.7
Inscribed circle diameter (m)	45
Circulatory roadway width (m)	9.3
Average entry width (m)	8.8
Number of lanes	2
Type of signalisation	Un-signalised
Type of grade	At-grade
Total accident (entry +circulatory lanes)	11
Truck accident (entry +circulatory lanes)	3
Harsh braking incident (entry +circulatory lanes)	280

Total traffic AADT (sum of entry traffic)	38999
Truck %	9.3
Inscribed circle diameter (m)	71
Circulatory roadway width (m)	11.8
Average entry width (m)	11.1
Number of lanes	3
Type of signalisation	Partially signalised
Type of grade	At-grade
Total accident (entry +circulatory lanes)	27
Truck accident (entry +circulatory lanes)	7
Harsh braking incident (entry +circulatory lanes)	169

Walting Street, A5/A34

Total traffic AADT (sum of entry traffic)	40053
Truck %	11.7
Inscribed circle diameter (m)	61
Circulatory roadway width (m)	9.3
Average entry width (m)	10.1
Number of lanes	2
Type of signalisation	Un-signalised
Type of grade	At-grade
Total accident (entry +circulatory lanes)	28
Truck accident (entry +circulatory lanes)	1
Harsh braking incident (entry +circulatory lanes)	300

Walsall Road, A5/B4154

Total traffic AADT (sum of entry traffic)	29953
Truck %	10
Inscribed circle diameter (m)	119
Circulatory roadway width (m)	9.8
Average entry width (m)	7.6
Number of lanes	2
Type of signalisation	Un-signalised
Type of grade	At-grade
Total accident (entry +circulatory lanes)	11
Truck accident (entry +circulatory lanes)	0
Harsh braking incident (entry +circulatory lanes)	251

Chester Road, A5/A452

Total traffic AADT (sum of entry traffic)	53234
Truck %	4.83
Inscribed circle diameter (m)	150
Circulatory roadway width (m)	12.5
Average entry width (m)	10.0
Number of lanes	3
Type of signalisation	Signalised
Type of grade	Grade-separated
Total accident (entry +circulatory lanes)	19
Truck accident (entry +circulatory lanes)	3
Harsh braking incident (entry +circulatory lanes)	395

Gilda Brook roundabout

Total traffic AADT (sum of entry traffic)	16362
Truck %	4.6
Inscribed circle diameter (m)	58
Circulatory roadway width (m)	7.3
Average entry width (m)	9.0
Number of lanes	2
Type of signalisation	Un-signalised
Type of grade	At-grade
Total accident (entry +circulatory lanes)	23
Truck accident (entry +circulatory lanes)	3
Harsh braking incident (entry +circulatory lanes)	5

Dramway roundabout

Total traffic AADT (sum of entry traffic)	57123
Truck %	3.2
Inscribed circle diameter (m)	239
Circulatory roadway width (m)	13.0
Average entry width (m)	9.2
Number of lanes	2
Type of signalisation	Partially signalised
Type of grade	Grade-separated
Total accident (entry +circulatory lanes)	62
Truck accident (entry +circulatory lanes)	2
Harsh braking incident (entry +circulatory lanes)	3

Abbey Hill roundabout

A5/A361

Total traffic AADT (sum of entry traffic)	11170
Truck %	12.8
Inscribed circle diameter (m)	57
Circulatory roadway width (m)	12.6
Average entry width (m)	8.8
Number of lanes	2
Type of signalisation	Un-signalised
Type of grade	At-grade
Total accident (entry +circulatory lanes)	5
Truck accident (entry +circulatory lanes)	1
Harsh braking incident (entry +circulatory lanes)	11

A5/B5440

Total traffic AADT (sum of entry traffic)	47417
Truck %	5
Inscribed circle diameter (m)	147
Circulatory roadway width (m)	15.0
Average entry width (m)	9.6
Number of lanes	3
Type of signalisation	Partially signalised (un-signalised circulatory)
Type of grade	Grade-separated
Total accident (entry +circulatory lanes)	46
Truck accident (entry +circulatory lanes)	4
Harsh braking incident (entry +circulatory lanes)	6

A607/A46

Total traffic AADT (sum of entry traffic)	27870
Truck %	5.8
Inscribed circle diameter (m)	54
Circulatory roadway width (m)	7.4
Average entry width (m)	8.1
Number of lanes	2
Type of signalisation	Un-signalised
Type of grade	At-grade
Total accident (entry +circulatory lanes)	14
Truck accident (entry +circulatory lanes)	2
Harsh braking incident (entry +circulatory lanes)	7

Total traffic AADT (sum of entry traffic)	34075
Truck %	7.1
Inscribed circle diameter (m)	124
Circulatory roadway width (m)	9.5
Average entry width (m)	7.0
Number of lanes	2
Type of signalisation	Un-signalised
Type of grade	Grade-separated
Total accident (entry +circulatory lanes)	36
Truck accident (entry +circulatory lanes)	3
Harsh braking incident (entry +circulatory lanes)	5

A46/A606

Total traffic AADT (sum of entry traffic)	18958
Truck %	4.6
Inscribed circle diameter (m)	40
Circulatory roadway width (m)	10.0
Average entry width (m)	7.1
Number of lanes	2
Type of signalisation	Un-signalised
Type of grade	At-grade
Total accident (entry +circulatory lanes)	6
Truck accident (entry +circulatory lanes)	2
Harsh braking incident (entry +circulatory lanes)	13

A6075/A616

Total traffic AADT (sum of entry traffic)	11605
Truck %	5.8
Inscribed circle diameter (m)	71
Circulatory roadway width (m)	9.7
Average entry width (m)	9.2
Number of lanes	2
Type of signalisation	Un-signalised
Type of grade	At-grade
Total accident (entry +circulatory lanes)	7
Truck accident (entry +circulatory lanes)	2
Harsh braking incident (entry +circulatory lanes)	0

A63/A1246

Total traffic AADT (sum of entry traffic)	12857
Truck %	8.3
Inscribed circle diameter (m)	60
Circulatory roadway width (m)	8.3
Average entry width (m)	7.4
Number of lanes	2
Type of signalisation	Un-signalised
Type of grade	At-grade
Total accident (entry +circulatory lanes)	16
Truck accident (entry +circulatory lanes)	1
Harsh braking incident (entry +circulatory lanes)	1

A19/ Thirsk Road

Total traffic AADT (sum of entry traffic)	14081
Truck %	6.5
Inscribed circle diameter (m)	49
Circulatory roadway width (m)	8.7
Average entry width (m)	7.7
Number of lanes	2
Type of signalisation	Un-signalised
Type of grade	At-grade
Total accident (entry +circulatory lanes)	16
Truck accident (entry +circulatory lanes)	3
Harsh braking incident (entry +circulatory lanes)	1

A64/A1039

Total traffic AADT (sum of entry traffic)	37433
Truck %	7.6
Inscribed circle diameter (m)	72
Circulatory roadway width (m)	10.4
Average entry width (m)	8.2
Number of lanes	2
Type of signalisation	Un-signalised
Type of grade	At-grade
Total accident (entry +circulatory lanes)	21
Truck accident (entry +circulatory lanes)	3
Harsh braking incident (entry +circulatory lanes)	15

Mile End roundabout

Total traffic AADT (sum of entry traffic)	20074
Truck %	3
Inscribed circle diameter (m)	224
Circulatory roadway width (m)	13.0
Average entry width (m)	9.8
Number of lanes	3
Type of signalisation	Signalised
Type of grade	Grade-separated
Total accident (entry +circulatory lanes)	55
Truck accident (entry +circulatory lanes)	2
Harsh braking incident (entry +circulatory lanes)	0

J4 on the M53

Total traffic AADT (sum of entry traffic)	16519
Truck %	5.2
Inscribed circle diameter (m)	145
Circulatory roadway width (m)	9.3
Average entry width (m)	9.8
Number of lanes	2
Type of signalisation	Un-signalised
Type of grade	Grade-separated
Total accident (entry +circulatory lanes)	16
Truck accident (entry +circulatory lanes)	0
Harsh braking incident (entry +circulatory lanes)	193

J9 on the M53

Total traffic AADT (sum of entry traffic)	36370
Truck %	5.4
Inscribed circle diameter (m)	197
Circulatory roadway width (m)	11.5
Average entry width (m)	8.6
Number of lanes	2
Type of signalisation	Un-signalised
Type of grade	Grade-separated
Total accident (entry +circulatory lanes)	36
Truck accident (entry +circulatory lanes)	4
Harsh braking incident (entry +circulatory lanes)	20

J11 on the M62

Total traffic AADT (sum of entry traffic)	74966
Truck %	11.2
Inscribed circle diameter (m)	207
Circulatory roadway width (m)	11.0
Average entry width (m)	13.7
Number of lanes	2
Type of signalisation	Partially signalised
Type of grade	Grade-separated
Total accident (entry +circulatory lanes)	147
Truck accident (entry +circulatory lanes)	33
Harsh braking incident (entry +circulatory lanes)	671

J3 on the M27

Total traffic AADT (sum of entry traffic)	71377
Truck %	13.3
Inscribed circle diameter (m)	198
Circulatory roadway width (m)	12.0
Average entry width (m)	9.8
Number of lanes	3
Type of signalisation	Signalised
Type of grade	Grade-separated
Total accident (entry +circulatory lanes)	129
Truck accident (entry +circulatory lanes)	39
Harsh braking incident (entry +circulatory lanes)	333

A1/A14

Total traffic AADT (sum of entry traffic)	39769
Truck %	22.5
Inscribed circle diameter (m)	197
Circulatory roadway width (m)	14.0
Average entry width (m)	10.9
Number of lanes	3
Type of signalisation	Signalised
Type of grade	Grade-separated
Total accident (entry +circulatory lanes)	170
Truck accident (entry +circulatory lanes)	54
Harsh braking incident (entry +circulatory lanes)	456

A14/A141

A617/A616/A46

Total traffic AADT (sum of entry traffic)	43170
Truck %	9
Inscribed circle diameter (m)	76
Circulatory roadway width (m)	11.0
Average entry width (m)	8.9
Number of lanes	2
Type of signalisation	Partially signalised (circulatory un-signalised)
Type of grade	At-grade
Total accident (entry +circulatory lanes)	99
Truck accident (entry +circulatory lanes)	27
Harsh braking incident (entry +circulatory lanes)	154

B6166/A46

Total traffic AADT (sum of entry traffic)	52265
Truck %	10
Inscribed circle diameter (m)	61
Circulatory roadway width (m)	9.0
Average entry width (m)	10.4
Number of lanes	3
Type of signalisation	Un-signalised
Type of grade	At-grade
Total accident (entry +circulatory lanes)	119
Truck accident (entry +circulatory lanes)	20
Harsh braking incident (entry +circulatory lanes)	177

A46/A17

Total traffic AADT (sum of entry traffic)	54633
Truck %	9.4
Inscribed circle diameter (m)	62
Circulatory roadway width (m)	11.0
Average entry width (m)	10.9
Number of lanes	3 (circulatory lanes is 2)
Type of signalisation	Un-signalised
Type of grade	At-grade
Total accident (entry +circulatory lanes)	51
Truck accident (entry +circulatory lanes)	13
Harsh braking incident (entry +circulatory lanes)	197

A19/A645

Total traffic AADT (sum of entry traffic)	15684
Truck %	10.4
Inscribed circle diameter (m)	38
Circulatory roadway width (m)	6.0
Average entry width (m)	9.0
Number of lanes	2
Type of signalisation	Un-signalised
Type of grade	At-grade
Total accident (entry +circulatory lanes)	10
Truck accident (entry +circulatory lanes)	2
Harsh braking incident (entry +circulatory lanes)	168

A63/A19

Total traffic AADT (sum of entry traffic)	42466
Truck %	5.2
Inscribed circle diameter (m)	81
Circulatory roadway width (m)	12.0
Average entry width (m)	10.7
Number of lanes	2
Type of signalisation	Un-signalised
Type of grade	At-grade
Total accident (entry +circulatory lanes)	12
Truck accident (entry +circulatory lanes)	2
Harsh braking incident (entry +circulatory lanes)	304

A1237/A64

Total traffic AADT (sum of entry traffic)	19872
Truck %	7
Inscribed circle diameter (m)	133
Circulatory roadway width (m)	11.0
Average entry width (m)	7.9
Number of lanes	2
Type of signalisation	Signalised
Type of grade	At-grade
Total accident (entry +circulatory lanes)	62
Truck accident (entry +circulatory lanes)	9
Harsh braking incident (entry +circulatory lanes)	59

Appendix E

Estimated Random Parameters Negative Binomial Model Procedure

- Firstly we add the first variable, using fixed parameters model

```
--> negbin;lhs=Y;rhs=one,x1
    ;rpm;pts=200;halton
    ;marginal effects$
```

Note that (b/St.Er) is the *t*-stat >1.65and is significant, so it will remain in the model, then adding the second variable

Variable	Coefficient	Standard Error	b/St.Er.	P[|Z|>z]	Mean of X
--------+Nonrandom parameters					
Constant	4.38418950	.14735241	29.753	.0000	
X1	-.32933691	.18408411	-1.789	.0736	.55714286
X2	-1.17419375	.21302161	-5.512	.0000	.17142857
--------+Dispersion parameter for NegBin distribution					
ScalParm	2.32658022	.56534891	4.115	.0000	

Second variable is significant so it will remain in the model, adding the third variable

Variable	Coefficient	Standard Error	b/St.Er.	P[|Z|>z]	Mean of X
Constant	4.60040865	.02678763	171.736	.0000	
X1	-.27755951	.03192725	-8.693	.0000	.55714286
X2	-1.42241914	.07312884	-19.451	.0000	.17142857
X3	-.38537937	.03208462	-12.011	.0000	.55714286

The third variable is significant, so it will remain in the model, then adding the fourth variable

Variable	Coefficient	Standard Error	b/St.Er.	P[|Z|>z]	Mean of X
--------+Nonrandom parameters					
Constant	4.58708319	.28284705	16.218	.0000	
X1	-.32840305	.17238299	-1.905	.0568	.55714286
X2	-1.37781002	.32169424	-4.283	.0000	.17142857
X3	-.35810876	.28307788	-1.265	.2059	.55714286
X4	.08513045	.38461613	.221	.8248	.17142857
--------+Dispersion parameter for NegBin distribution					
ScalParm	2.50430160	.59012936	4.244	.0000	

X4 and x3 will be insignificant and is removed, adding x5

Variable	Coefficient	Standard Error	b/St.Er.	P[|Z|>z]	Mean of X
Nonrandom parameters					
Constant	3.36234952	.20658303	16.276	.0000	
X1	-.39874638	.14658097	-2.720	.0065	.55714286
X2	-.60674205	.19885597	-3.051	.0023	.17142857
X5	.00576849	.00123270	4.680	.0000	158.285714
Dispersion parameter for NegBin distribution					
ScalParm	2.94921810	.69880312	4.220	.0000	

This process continues until adding all variables that considered to be estimated to find their influence on dependent variables, until we get the best fixed parameter model:

Variable	Coefficient	Standard Error	b/St.Er.	P[|Z|>z]	Mean of X
Nonrandom parameters					
Constant	-.91973421	1.32858518	-.692	.4888	
X2	-.37653180	.20969751	-1.796	.0726	.17142857
X5	.00335192	.00127499	2.629	.0086	158.285714
X9	-.56979905	.14586791	-3.906	.0001	.40000000
X10	.05789465	.03282380	1.764	.0778	6.97457143
X11	.39058549	.11367843	3.436	.0006	10.6753286
Dispersion parameter for NegBin distribution					
ScalParm	4.35143069	1.00188629	4.343	.0000	

In order to build a random-parameter model all the variables that were fixed (x2, x5, x9, x10, x11) and all the variables that were insignificant (x1, x3, x4, x6, x7, x8) are tested for random parameters the (fcn) statement in the model is used for random parameters.

Adding x1 to random parameters model

```
--> negbin;lhs=Y;rhs=one,x2,x5,x9,x10,x11,x1
    ;rpm;pts=200;halton
    ;fcn=x1(n);marginal effects$
```

Variable	Coefficient	Standard Error	b/St.Er.	P[|Z|>z]	Mean of X
Nonrandom parameters					
Constant	-.75437696	1.37389016	-.549	.5829	
X2	-.34701130	.22634492	-1.533	.1252	.17142857
X5	.00359150	.00127928	2.807	.0050	158.285714
X9	-.52912729	.14523375	-3.643	.0003	.40000000
X10	.05828811	.03211237	1.815	.0695	6.97457143
X11	.37379924	.11937370	3.131	.0017	10.6753286
Means for random parameters					
X1	-.08766474	.14476267	-.606	.5448	.55714286
Scale parameters for dists. of random parameters					
X1	.00776991	.08445208	.092	.9267	
Dispersion parameter for NegBin distribution					
ScalParm	4.37305090	1.02780736	4.255	.0000	

X1 is insignificant in random parameters model; when mean and standard deviation was found to be not significant according to *t*-stat (outlined) so x1 should be removed from the model.

Adding x2 to the random parameters statement

Variable	Coefficient	Standard Error	b/St.Er.	P[|Z|>z]	Mean of X
Nonrandom parameters					
Constant	-1.04382707	1.29591976	-.805	.4205	
X5	.00340901	.00125552	2.715	.0066	158.285714
X9	-.55005249	.14393184	-3.822	.0001	.40000000
X10	.05934036	.03285806	1.806	.0709	6.97457143
X11	.39960419	.11012198	3.629	.0003	10.6753286
Means for random parameters					
X2	-.39452195	.21396122	-1.844	.0652	.17142857
Scale parameters for dists. of random parameters					
X2	.22319755	.17414484	1.282	.2000	
Dispersion parameter for NegBin distribution					
ScalParm	4.46850474	1.03043312	4.337	.0000	

X2 is removed from the random statement (see *t-stat* for scale parameters <1.65) but remains fixed as the mean of the variable is statistically found to be significant (-1.8>-1.65), adding x3.

Variable	Coefficient	Standard Error	b/St.Er.	P[|Z|>z]	Mean of X
Nonrandom parameters					
Constant	-.41840236	1.44755974	-.289	.7726	
X2	-.52425659	.24299949	-2.157	.0310	.17142857
X5	.00323736	.00127543	2.538	.0111	158.285714
X9	-.56216442	.13966892	-4.025	.0001	.40000000
X10	.05720841	.02899103	1.973	.0485	6.97457143
X11	.35618983	.12434136	2.865	.0042	10.6753286
Means for random parameters					
X3	-.17307971	.17482546	-.990	.3222	.55714286
Scale parameters for dists. of random parameters					
X3	.13901017	.08321219	1.671	.0948	
Dispersion parameter for NegBin distribution					
ScalParm	4.65211165	1.22076421	3.811	.0001	

X3 is significant as a random parameter (standard deviation is statistically different from zero as indicated by *t-stat*), adding x4

```
--> negbin;lhs=Y;rhs=one,x2,x5,x9,x10,x11,x3,x4
    ;rpm;pts=200;halton
    ;fcn=x3(n),x4(n);marginal effects$
```

Variable	Coefficient	Standard Error	b/St.Er.	P[|Z|>z]	Mean of X
Nonrandom parameters					
Constant	-.35309019	1.30640198	-.270	.7869	
X2	-.25957594	.29645770	-.876	.3813	.17142857
X5	.00410663	.00111866	3.671	.0002	158.285714
X9	-.64047351	.12437800	-5.149	.0000	.40000000
X10	.05219184	.02006749	2.601	.0093	6.97457143
X11	.32499667	.11237857	2.892	.0038	10.6753286
Means for random parameters					
X3	-.01829731	.21457499	-.085	.9320	.55714286
X4	.18137225	.23786888	.762	.4458	.17142857
Scale parameters for dists. of random parameters					
X3	.27534016	.07963621	0.576	.0005	
X4	.38586505	.11697601	0.283	.0010	
Dispersion parameter for NegBin distribution					
ScalParm	6.59374945	1.62374192	4.061	.0000	

X3 and x4 should be removed from the model, when mean and standard deviation was found to be not statistically significant according to *t*-stat they have to be removed from the model. In addition after adding x3 and x4, x2 became insignificant and it is removed from the model.

Adding x5 to the model as a random

Variable	Coefficient	Standard Error	b/St.Er.	P[|Z|>z]	Mean of X
Nonrandom parameters					
Constant	-.86658696	.99620734	-.870	.3844	
X9	-.63571081	.12939867	-4.913	.0000	.40000000
X10	.05277032	.02143025	2.462	.0138	6.97457143
X11	.34903471	.09565602	3.649	.0003	10.6753286
Means for random parameters					
X5	.00486852	.00107997	4.508	.0000	158.285714
Scale parameters for dists. of random parameters					
X5	.543196D-04	.00030638	.177	.8593	
Dispersion parameter for NegBin distribution					
ScalParm	6.20985480	1.50994637	4.113	.0000	

X5 is removed from the random statement but remain fixed as the mean of the variable is significant. This process will be applied to other x6, x7 x8, x9, x10, and x11 until to find their significance as a random variable. Below is the best random-parameter model in which x5, x9, and x11 found to be fixed in the random parameters model, and x10 was found to vary across the observations in the model as the standard deviation of the variable is statistically different from zero as indicated by *t-stat* outlined for the x10 scale parameters.

```
--> negbin;lhs=Y;rhs=one,x5,x9,x10,x11
    ;rpm;pts=200;halton
    ;fcn=x10(n);marginal effects$
```

Variable	Coefficient	Standard Error	b/St.Er.	P[|Z|>z]	Mean of X
---------+Nonrandom parameters					
Constant	-1.45568045	.85745978	-1.698	.0896	
X5	.00498050	.00081314	6.125	.0000	158.285714
X9	-.57702925	.09961131	-5.793	.0000	.40000000
X11	.40280665	.08136405	4.951	.0000	10.6753286
---------+Means for random parameters					
X10	.06047130	.01372978	4.404	.0000	6.97457143
---------+Scale parameters for dists. of random parameters					
X10	.05478512	.00632302	8.664	.0000	
---------+Dispersion parameter for NegBin distribution					
ScalParm	10.3498499	2.32421817	4.453	.0000	

In order to compare this model to the fixed parameter model the same model will be run in the program without fcn statement,

```
--> negbin;lhs=Y;rhs=one,x5,x9,x10,x11
    ;rpm;pts=200;halton
    ;marginal effects$
```

Variable	Coefficient	Standard Error	b/St.Er.	P[|Z|>z]	Mean of X
---------+Nonrandom parameters					
Constant	-1.93836381	1.11476848	-1.739	.0821	
X5	.00416536	.00125029	3.332	.0009	158.285714
X9	-.55854368	.14737270	-3.790	.0002	.40000000
X10	.06410603	.03321172	1.930	.0536	6.97457143
X11	.46406307	.09583017	4.843	.0000	10.6753286
---------+Dispersion parameter for NegBin distribution					
ScalParm	4.16237360	.86339826	4.821	.0000	

Appendix F

Reported Contributory Factors at the Selected Locations

Table (F-1) Highest Contributory Factor at the Selected Locations

Roundabouts	Highest Contributory Factor
J6 on the M4	Following too close
J11 on the M4	Failed to look properly
J13 on the M4	Poor turn or manoeuvre, Following too close
J14 on the M4	Failed to look properly and Sudden braking
J15 on the M4	Failed to judge other person's path or speed, Failed to look properly, Following too close
J16 on the M4	Failed to look properly
J17 on the M4	Failed to judge other person's path or speed
J18 on the M4	Failed to judge other person's path or speed, Impaired by alcohol
J23 on the M4	Failed to judge other person's path or speed
J2 on the M5	Poor turn or manoeuvre
J3 on the M5	Failed to judge other person's path or speed
J4 on the M5	Failed to look properly
J19 on the M5	Disobeyed Give Way or Stop sign or markings
J21 on the M5	Aggressive driving
J27 on the M5	Failed to look properly
J2 on the M40	Failed to judge other person's path or speed
J15 on the M40	Failed to judge other person's path or speed, Junction overshoot, Disobeyed automatic traffic signal
J2 on the M42	Failed to judge other person's path or speed, Poor turn or manoeuvre
J5 on the M42	Failed to judge other person's path or speed, Careless, reckless or in a hurry
J11 on the M42	Failed to look properly
J1 on the M54	Failed to look properly
J6 on the M54	Failed to look properly
J2 on the M6	Failed to look properly
J9 on the M6	Failed to look properly
J10 on the M6	Failed to judge other person's path or speed
J11 on the M6	Sudden braking
J12 on the M6	Poor turn or manoeuvre, Following too close, Poor turn or manoeuvre, Illegal turn or direction of travel
J13 on the M6	Sudden braking
J16 on the M6	Sudden braking
J19 on the M6	Failed to judge other person's path or speed
J23 on the M6	Failed to look properly
J40 on the M6	Poor turn or manoeuvre
A14/A4141	Poor turn or manoeuvre
A14/A141	Poor turn or manoeuvre
A19/A63	Failed to judge other person's path or speed, Failed to look properly
A46/A17	Poor turn or manoeuvre
B6226/A46	Failed to look properly
A64/A1273	Poor turn or manoeuvre, Sudden braking
A645/A19	Failed to look properly, Sudden braking
B6166/A46	Failed to look properly

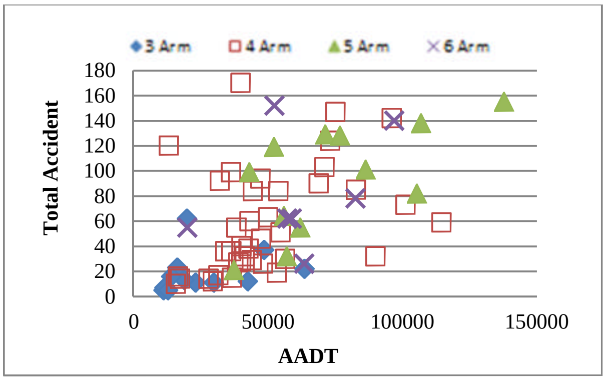
Table (F-1) Continued

J3 on the M27	Failed to look properly
Gilda Brook Roundabout	Failed to judge other person's path or speed, Poor turn or manoeuvre
Mytton Oak road	Failed to judge other person's path or speed
Lodge Ln, A460/Saredon Rd	Failed to judge other person's path or speed, Failed to look properly, Illness or disability, mental or physical
Walsall Road,A5/B4154	Failed to look properly
Walting Street, A5/A34	Poor turn or manoeuvre, Travelling too fast for conditions
J9 on the M53	Failed to judge other person's path or speed
J4 on the M53	Failed to look properly
Bromley Heath Roundabout	Failed to look properly
Dramway Roundabout	Following too close
Abbey Hill Roundabout	Failed to look properly
Mile End Roundabout	Failed to judge other person's path or speed
A5/A361	Learner or inexperienced driver/rider
B5440/A5	Failed to look properly
J11 on the M62	Failed to look properly and Failed to judge other person's path or speed
A1246/A63	Failed to look properly
A19/ Thirsk Road	Fatigue
A46/A606	Failed to judge other person's path or speed
A46/A607	Following too close
A616/A6075	Failed to look properly and
A64/A1039	Failed to look properly

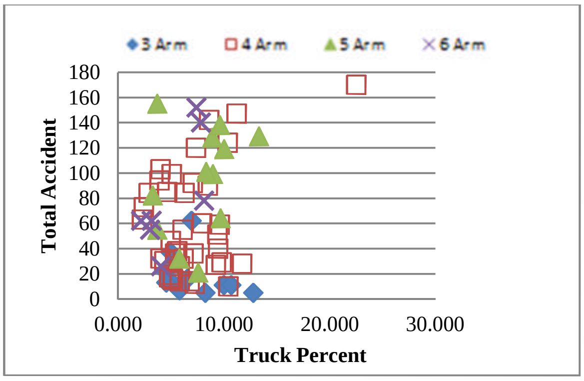
Appendix G

Total and Truck Accidents Characteristices with Traffic Characteristics

Characteristics of Total and Truck Accident at whole roundabouts

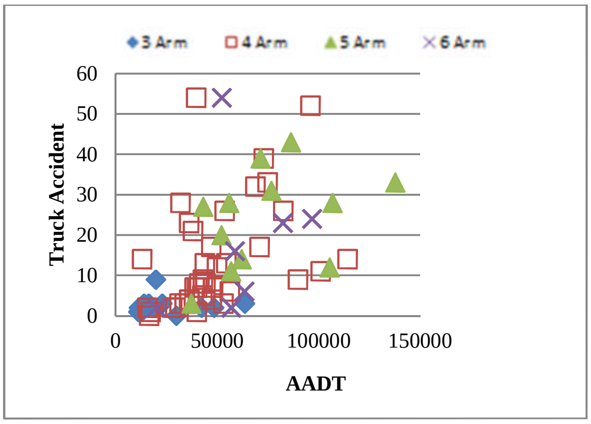


R^2=0.06 (3-arm), R^2=0.15 (4-arm), R^2=0.41 (5-arm), R^2=0.13 (6-arm)

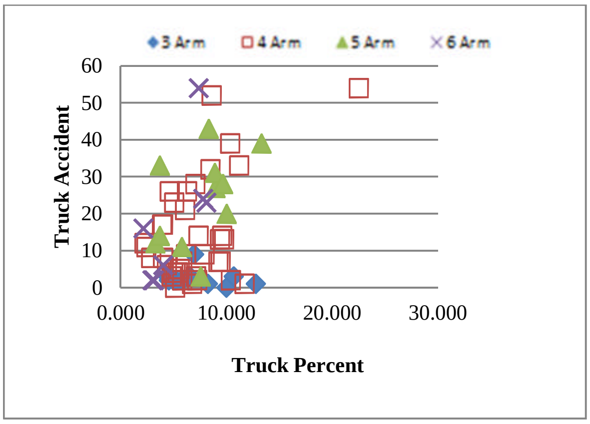


R^2=0.11 (3-arm), R^2=0.085 (4-arm), R^2=0.14 (5-arm), R^2=0.53 (6-arm)

Figure G-1Correlation between Total Accident , AADT, and Truck percentage based on number of Arms for Whole Roundabouts

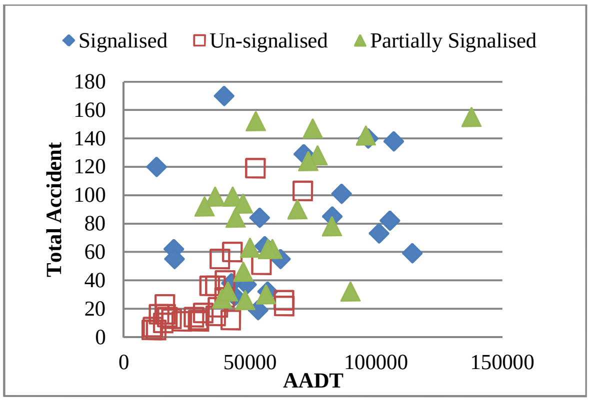


R^2=0.0006(3-arm), R^2=0.18 (4-arm), R^2=0.16 (5-arm), R^2=0.07 (6-arm)

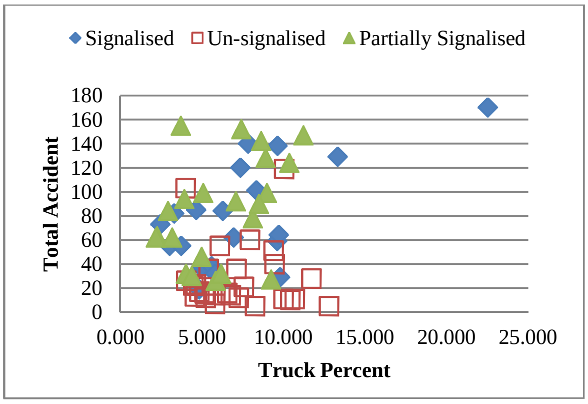


R^2=0.05(3-arm), R^2=0.24 (4-arm), R^2=0.24 (5-arm), R^2=0.48 (6-arm)

Figure G-2 Correlation between Truck Accident , AADT, and Truck percentage based on number of Arms for Whole Roundabouts

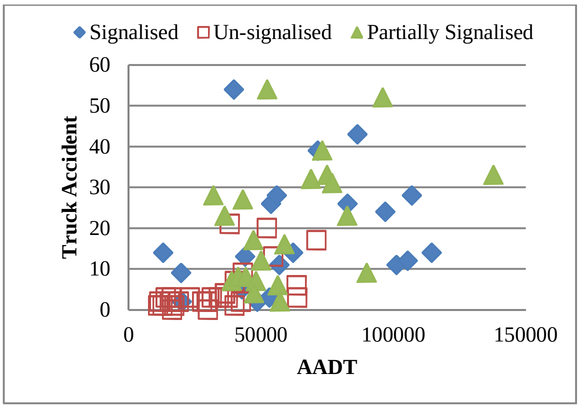


R^2=0.05 signal, R^2=0.43un-signal, R^2=0.22 partially signal

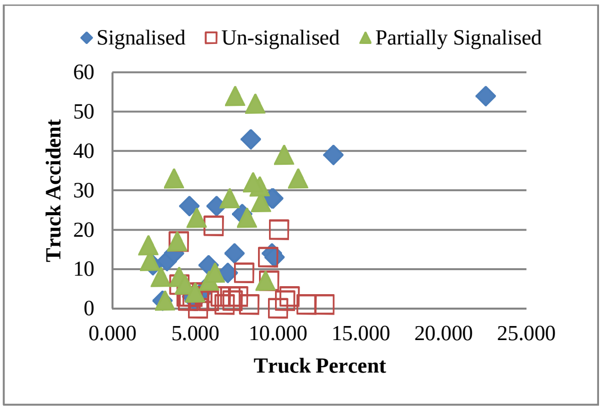


R^2=0.39 signal, R^2=5*10^{-8} un-signal, R^2=0.16 partially signal

Figure G-3 Correlation between Total Accident , AADT, and Truck percentage based on Traffic Control for Whole Roundabouts

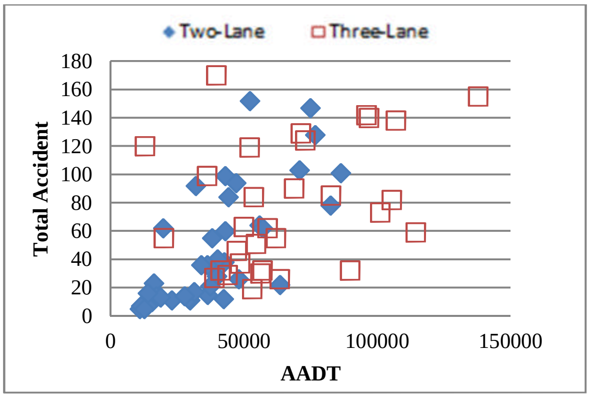


R^2=0.05 signal, R^2=0.34un-signal, R^2=0.16 partially signal

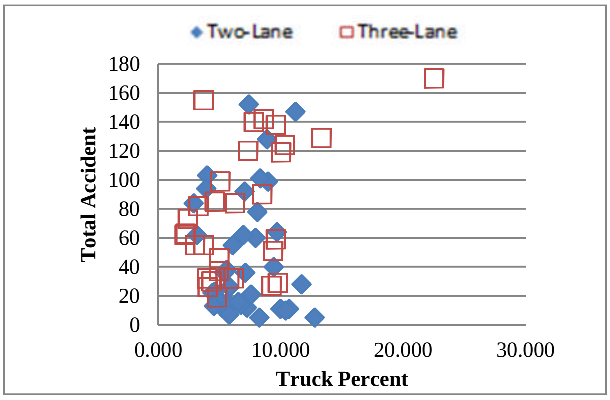


R^2=0.60 signal, R^2=0.0011 un-signal, R^2=0.33 partially signal

Figure G-4 Correlation between Truck Accident , AADT, and Truck percentage based on Traffic Control for Whole Roundabouts

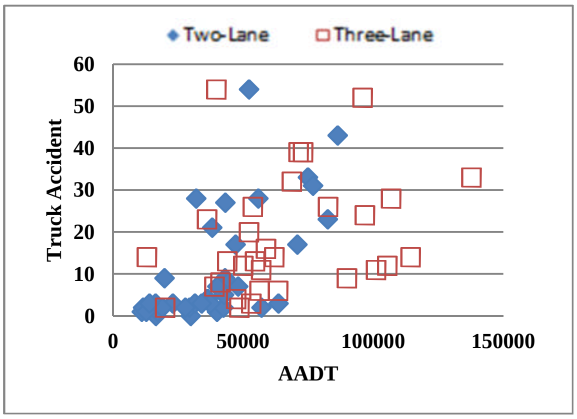


R^2=0.52 two-lane, R^2=0.11 three-lane

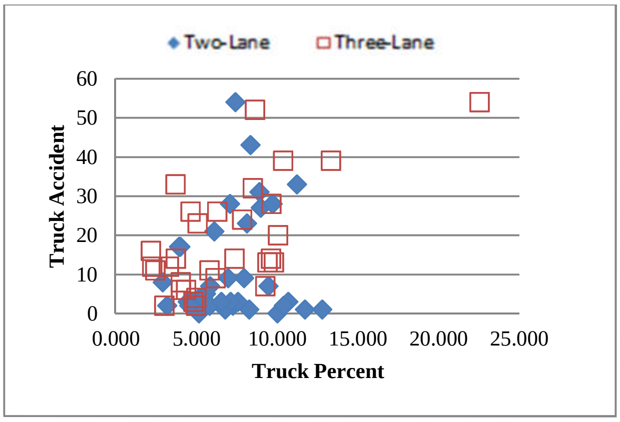


R^2=0.002 two-lane, R^2=0.23 three-lane

Figure G-5 Correlation between Total Accident , AADT, and Truck percentage based on number of Lanes for Whole Roundabouts

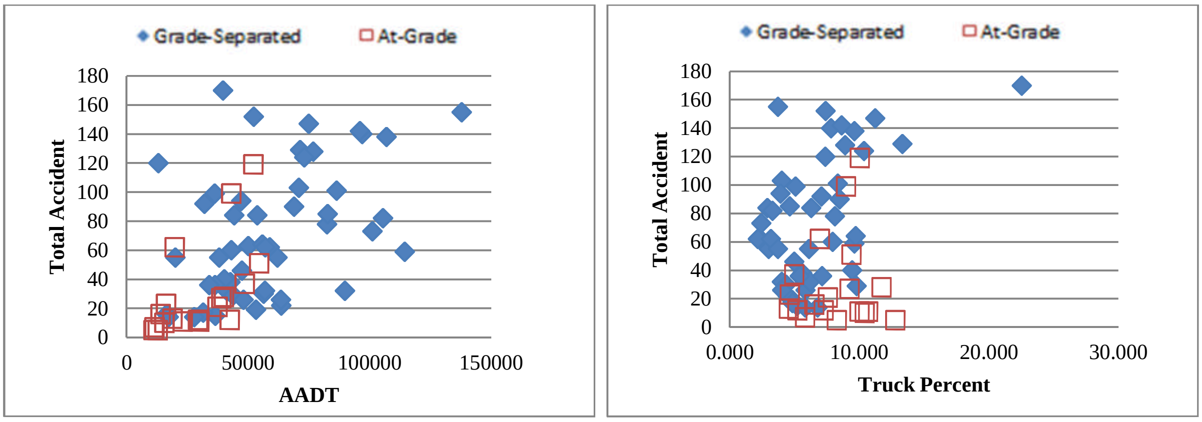


R^2=0.43 two-lane, R^2=0.096 three-lane



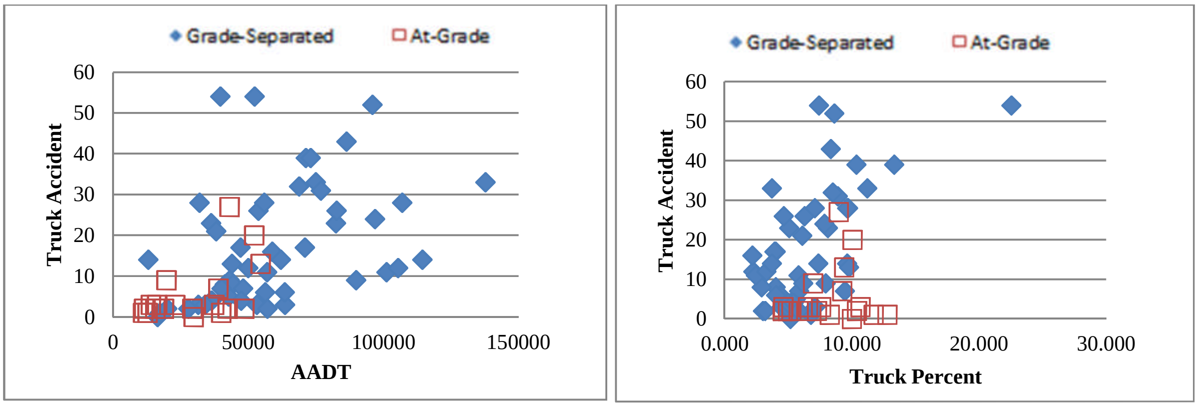
R^2=0.04 two-lane, R^2=0.41 three-lane

Figure G-6 Correlation between Truck Accident , AADT, and Truck percentage based on number of Lanes for Whole Roundabouts



R^2=0.22 grade-separated , R^2=0.36 at-grade R^2=0.23 grade-separated , R^2=0.014 at-grade

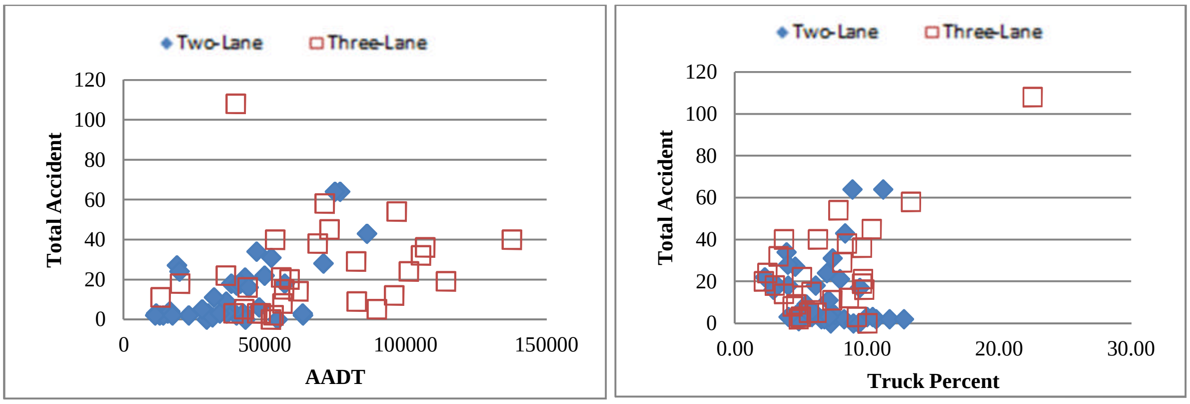
Figure G-7 Correlation between Total Accident , AADT, and Truck percentage based type of Grade for Whole Roundabouts



R^2=0.17 grade-separated , R^2=0.27 at-grade R^2=0.37 grade-separated , R^2=0.024 at-grade

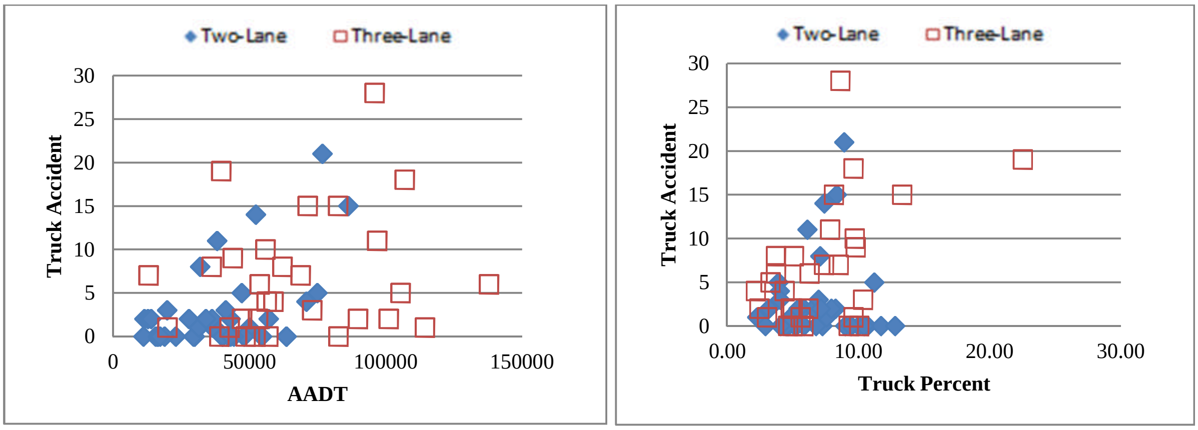
Figure G-8 Correlation between Truck Accident , AADT, and Truck percentage based type of Grade for Whole Roundabouts

Characteristics of Total and Truck Accident within Circulatory Lanes



R^2=0.39 two-lane, R^2=0.03 three-lane R^2=0.0006 two-lane, R^2=0.44 three-lane

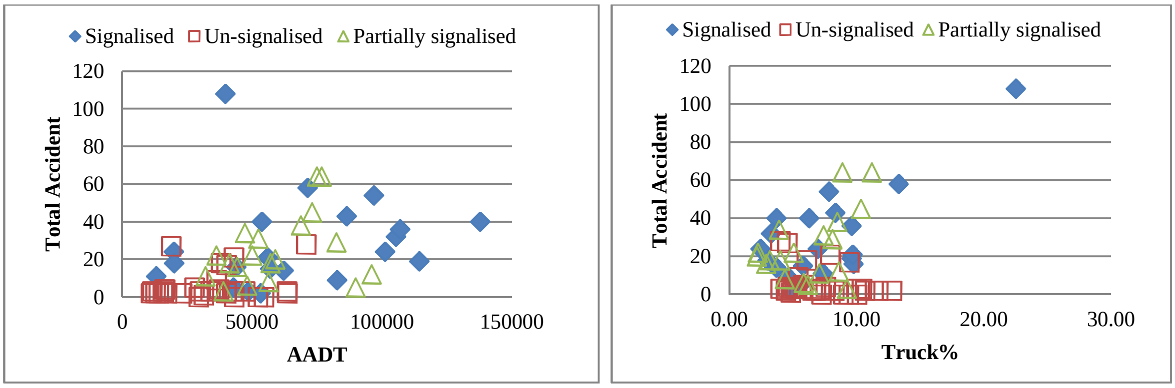
Figure G-9 Correlation between Total Accident , AADT, and Truck percentage based on number of Lanes within Circulatory



R^2=0.25 two-lane, R^2=0.04 three-lane

R^2=0.008 two-lane, R^2=0.27 three-lane

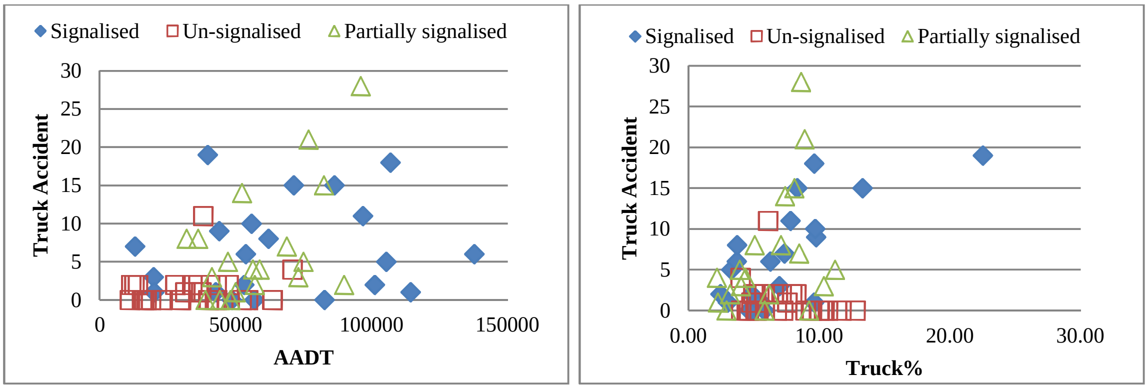
Figure G-10 Correlation between Truck Accident , AADT, and Truck percentage based on number of Lanes within Circulatory



R^2=0.03 signal, R^2=0.04un-signal, R^2=0.11 partially signal

R^2=0.58 signal, R^2=0.077 un-signal, R^2=0.23 partially signal

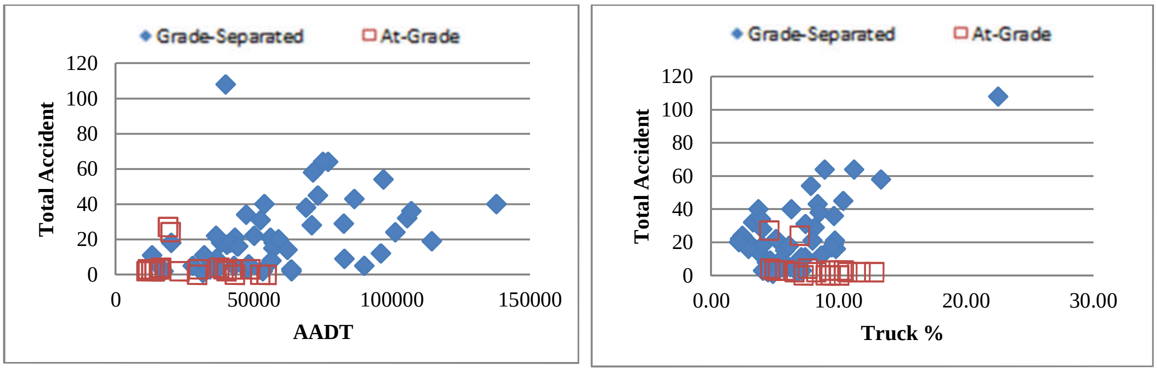
Figure G-11 Correlation between Total Accident , AADT, and Truck percentage based on Traffic Control within Circulatory



R^2=0.016 signal, R^2=0.011un-signal, R^2=0.016 partially signal

R^2=0.52 signal, R^2=0.07 un-signal, R^2=0.17 partially signal

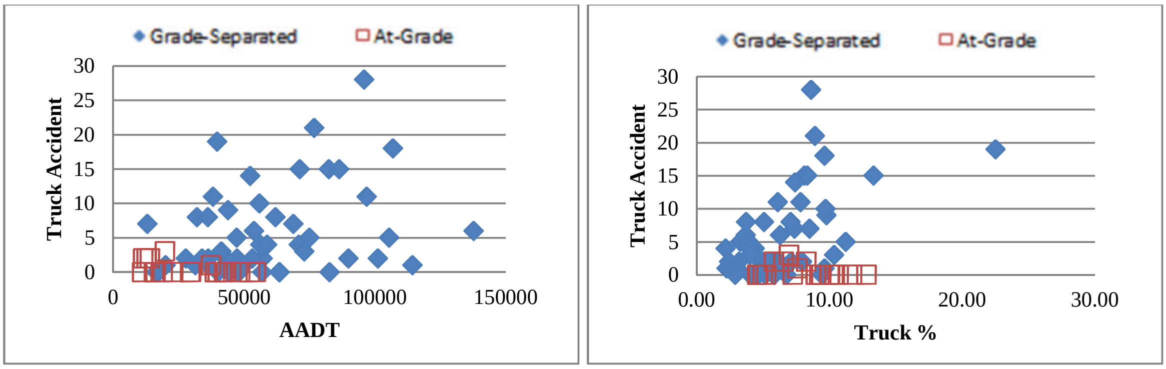
Figure G-12 Correlation between Truck Accident , AADT, and Truck percentage based on Traffic Control within Circulatory



R^2=0.12 grade-separated , R^2=0.09 at-grade

R^2=0.45 grade-separated , R^2=0.16 at-grade

Figure G-13 Correlation between Total Accident , AADT, and Truck percentage based on Grade Type within Circulatory

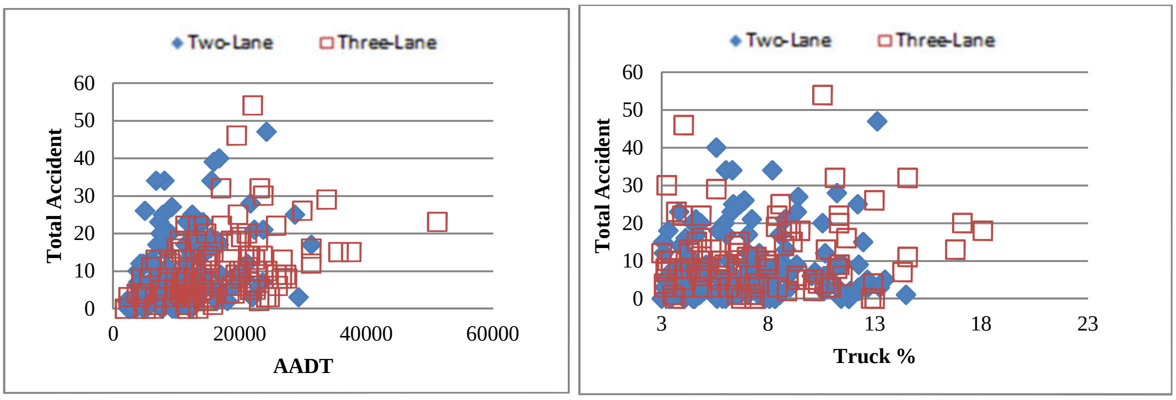


R^2=0.10 grade-separated , R^2=0.22 at-grade

R^2=0.31 grade-separated , R^2=0.07 at-grade

Figure G-14 Correlation between TruckAccident , AADT, and Truck percentage based on Grade Type within Circulatory

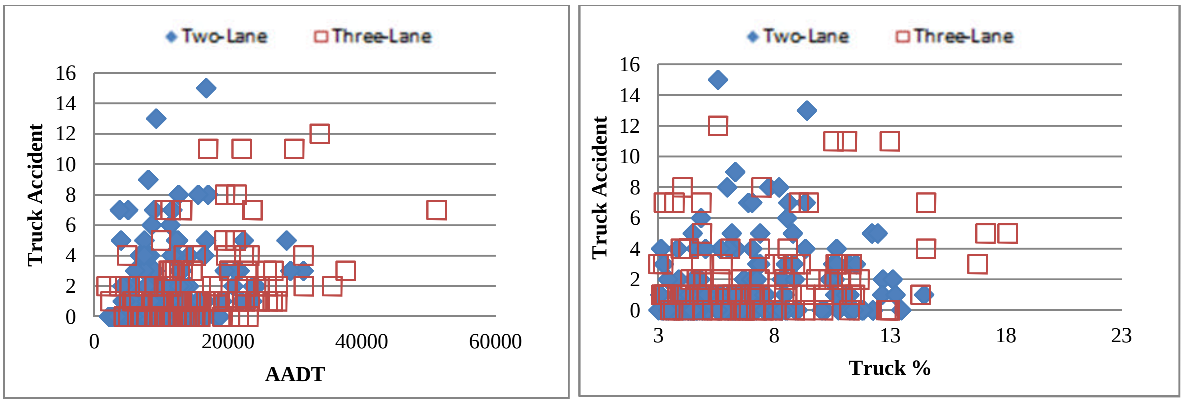
Characteristics Total and Truck Accidents at Approaches



R^2=0.14 two-lane, R^2=0.17 three-lane

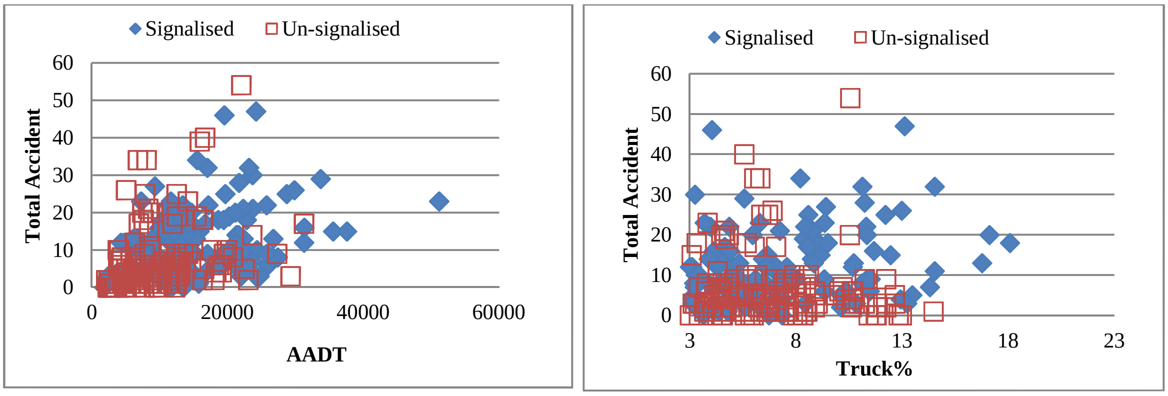
R^2=0.008 two-lane, R^2=0.03three-lane

Figure G-15 Correlation between Total Accident , AADT, and Truck percentage based on number of Lanes at Approaches



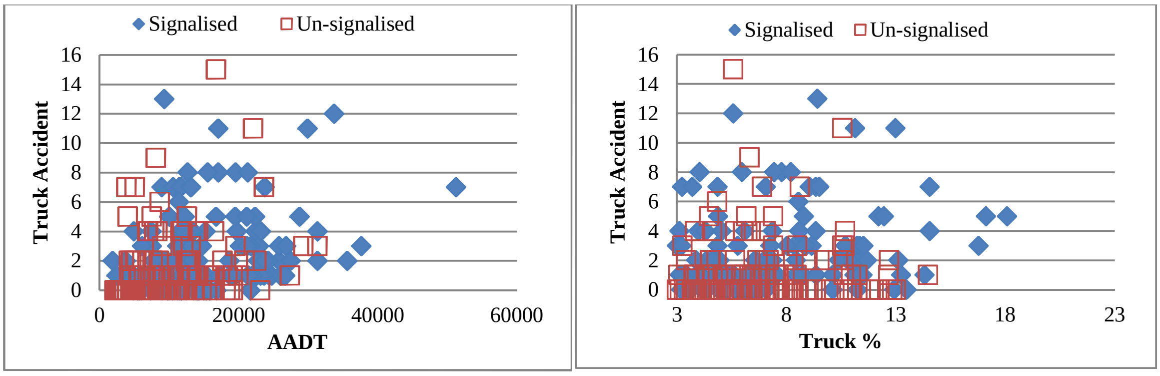
R^2=0.06 two-lane, R^2=0.13 three-lane R^2=0.008 two-lane, R^2=0.04 three-lane

Figure G-16 Correlation between Truck Accident , AADT, and Truck percentage based on number of Lanes at Approaches



R^2=0.13 signal, R^2=0.09un-signal R^2=0.06 signal, R^2=0.03 un-signal

Figure G-17 Correlation between Total Accident , AADT, and Truck percentage based on Traffic Control at Approaches



R^2=0.06 signal, R^2=0.06 un-signal R^2=0.07 signal, R^2=0.0008 un-signal

Figure G-18 Correlation between Truck Accident , AADT, and Truck percentage based on Traffic Control at Approaches

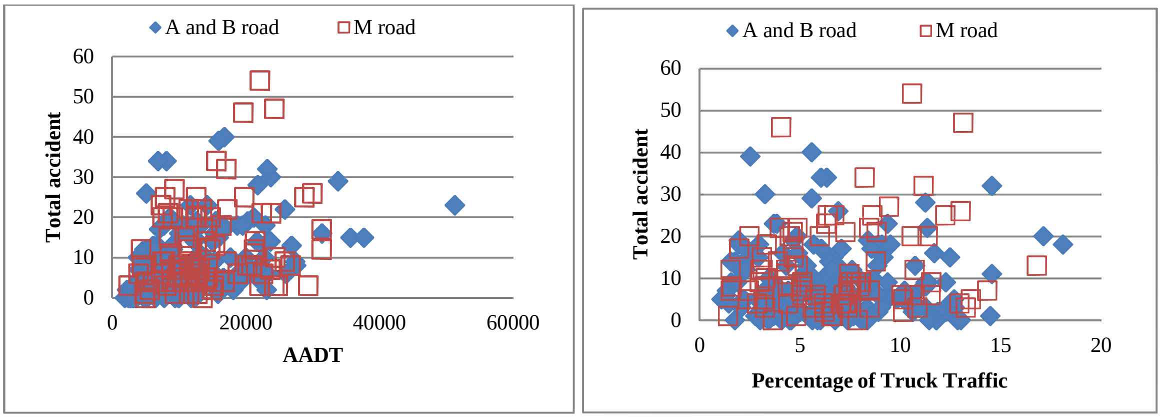


Figure G-19 Correlation between Trotal Accident , AADT, and Truck percentage based on Road Class At Approaches

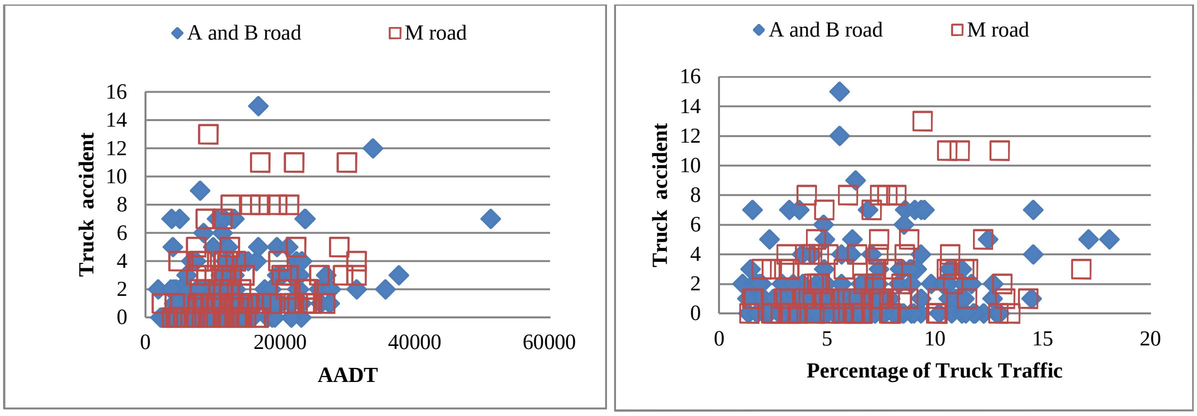
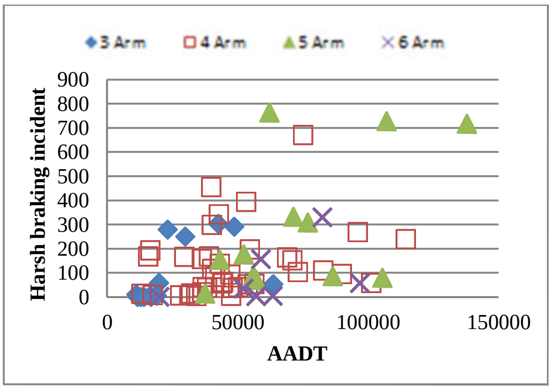
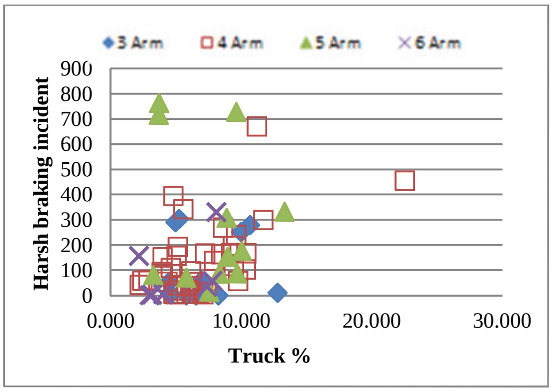


Figure G-20 Correlation between Truck Accident , AADT, and Truck percentage based on Road Class At Approaches

Appendix H
Harsh Braking Incidents Characteristices with Traffic Characteristics

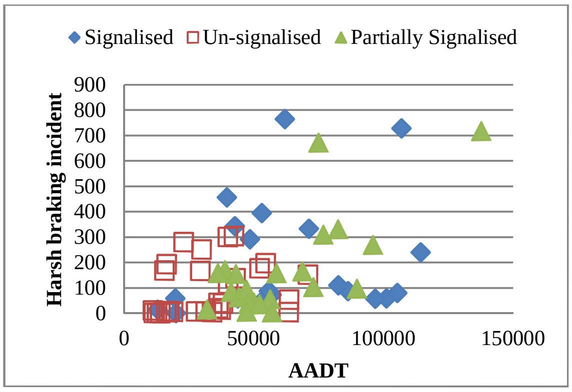
Characteristics of Harsh Braking Incident at Whole Roundabouts

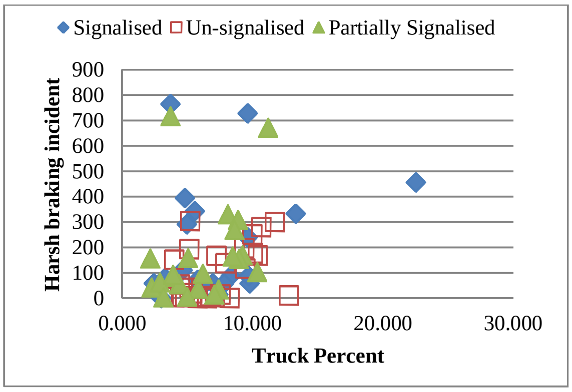




R^2=0.28 (3-arm), R^2=0.07 (4-arm), R^2=0.30 (5-arm), R^2=0. 21 (6-arm) R^2=0.01 (3-arm), R^2=0.30 (4-arm), R^2=0.05 (5-arm), R^2=0.16 (6-arm)

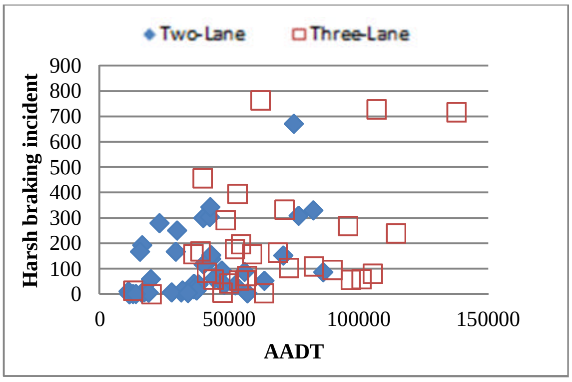
Figure H-1 Correlation between harsh braking incidents , AADT, and Truck percentage based on Number of Arms for Whole Roundabouts

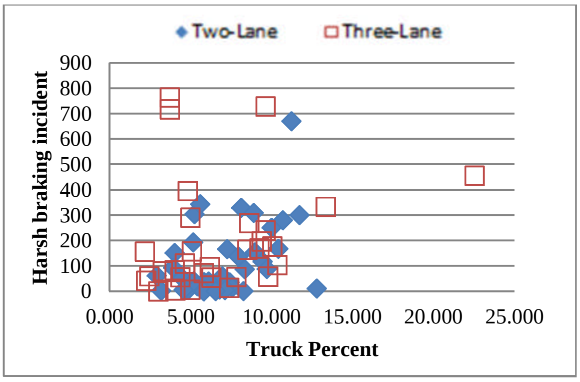




R^2=0.03 signal, R^2=0.06un-signal, R^2=0.52 partially signal R^2=0.06 signal, R^2=0.11 un-signal, R^2=0.19 partially signal

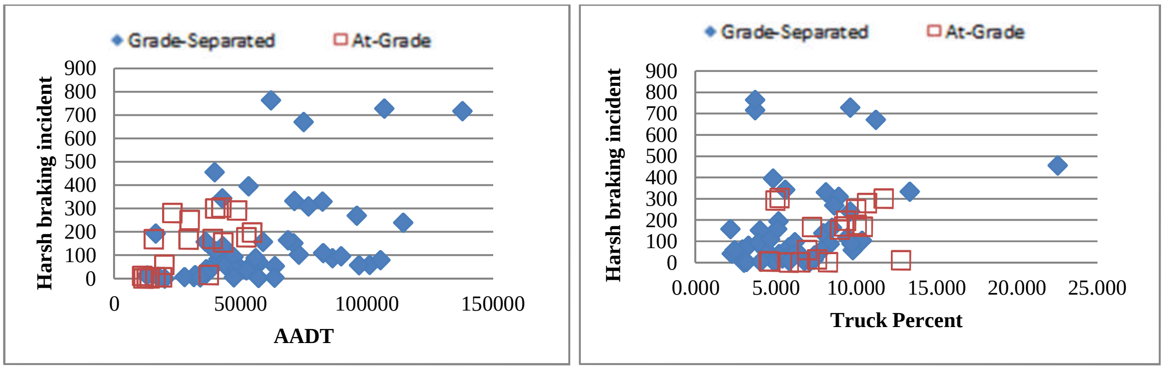
Figure H-2 Correlation between harsh braking incidents , AADT, and Truck percentage based on Traffic Control for Whole Roundabouts





R^2=0.19 two-lane, R^2=0.15 three-lane R^2=0.18 two-lane, R^2=0.06 three-lane

Figure H-3 Correlation between harsh braking incidents , AADT, and Truck percentage based on number of Lanes for Whole Roundabouts

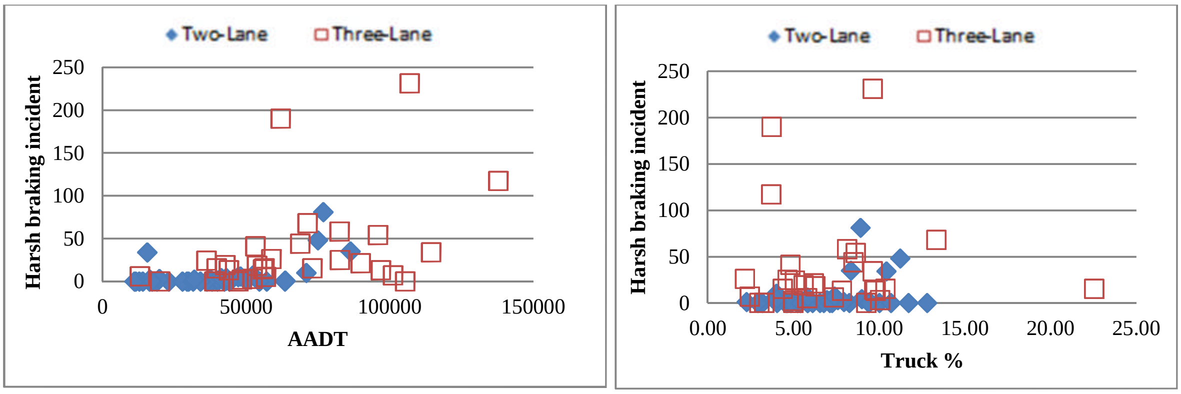


R^2=0.21 grade-separated , R^2=0.44 at-grade

R^2=0.01 grade-separated , R^2=0.08 at-grade

Figure H-4 Correlation between harsh braking incidents , AADT, and Truck percentage based on Type of Grade for Whole Roundabouts

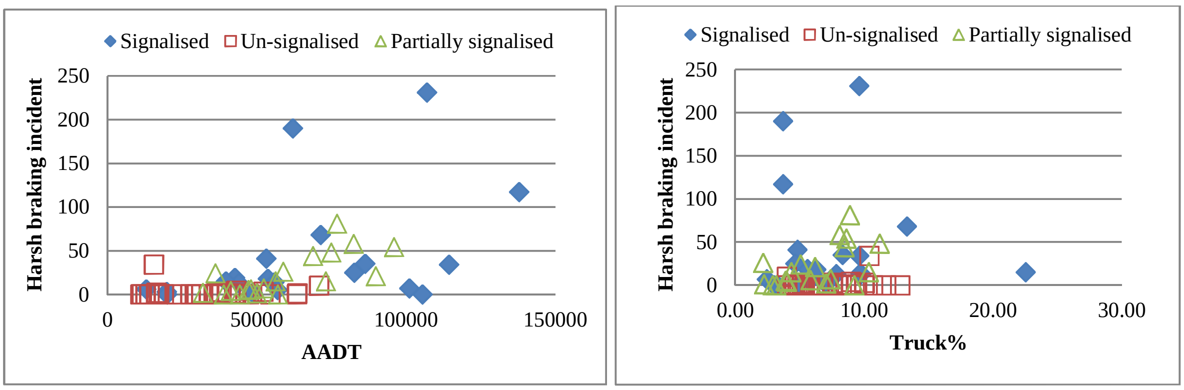
Characteristics of Harsh Braking Incident Within Circulatory Lanes



R^2=0.26 two-lane, R^2=0.17 three-lane

R^2=0.01two-lane, R^2=0.000006 three-lane

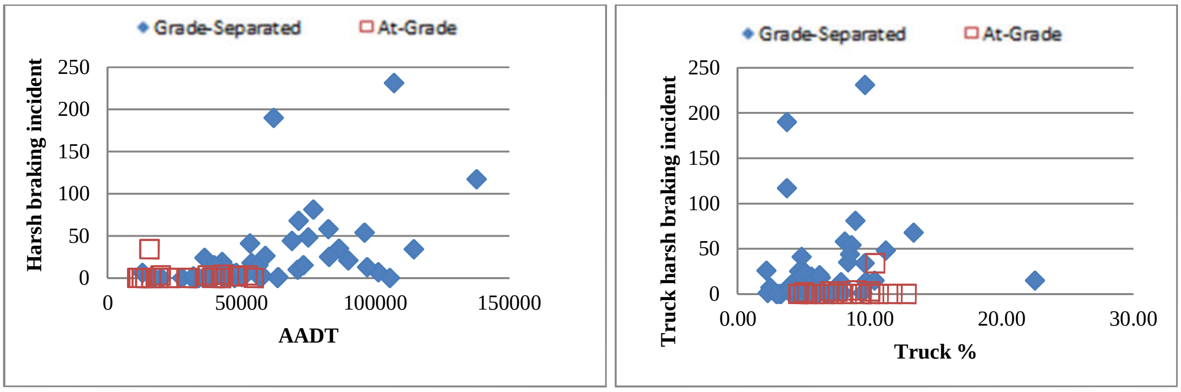
Figure H-5 Correlation between Harsh Braking Incident, AADT, and Truck percentage based on number of Lanes within Circulatory



R^2=0.16 signal, R^2=0.0021un-signal, R^2=0.52 partially signal

R^2=8*10^{-7} signal, R^2=0.04 un-signal, R^2=0.28 partially signal

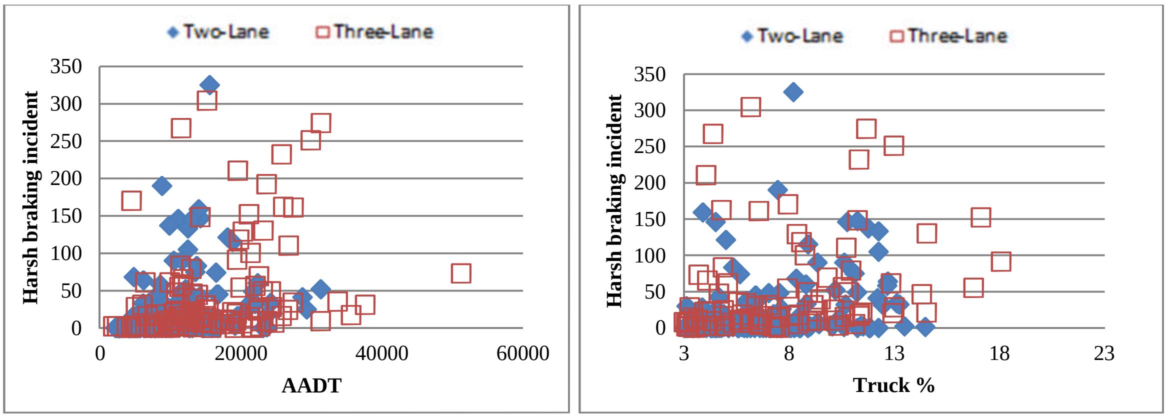
Figure H-6 Correlation between Harsh Braking Incident, AADT, and Truck percentage based on Traffic Control within Circulatory



R^2=0.25 grade-separated , R^2=0.02 at-grade R^2=0.02 grade-separated , R^2=0.045 at-grade

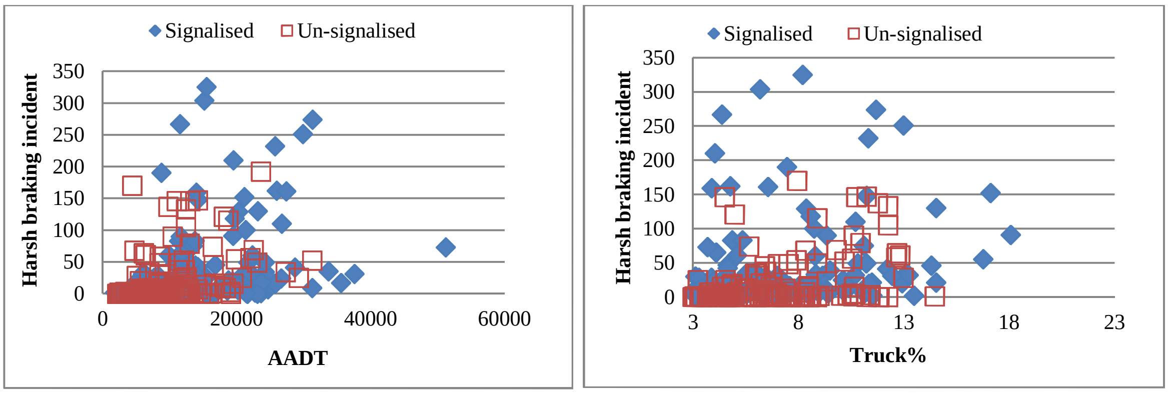
Figure H-7 Correlation between Harsh Braking Incident, AADT, and Truck percentage based on type of grade within Circulatory

Characteristics of Harsh Braking Incident at Approaches



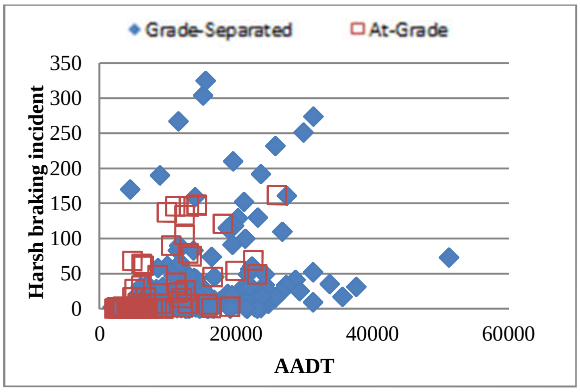
R^2=0.08 two-lane, R^2=0.08 three-lane R^2=0.06 two-lane, R^2=0.07 three-lane

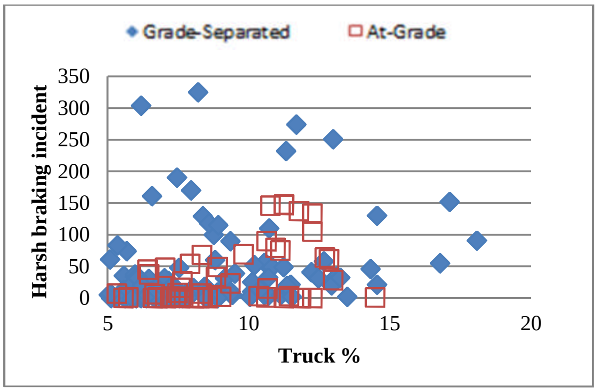
Figure H-8 Correlation between Harsh Braking Incident, AADT, and Truck percentage based on number of Lanes at approaches



R^2=0.08 signal, R^2=0.13un-signal R^2=0.07 signal, R^2=0.07 un-signal

Figure H-9 Correlation between Harsh Braking Incident, AADT, and Truck percentage based on Traffic Control at approaches





R^2=0.10 grade-separated , R^2=0.31 at-grade R^2=0.07 grade-separated , R^2=0.07 at-grade

Figure H-10 Correlation between Harsh Braking Incident, AADT, and Truck percentage based on Type of Grade at approaches

Appendix I

Harsh Braking Incidents to Total and Truck Accidents Based on Different Approach Characteristics

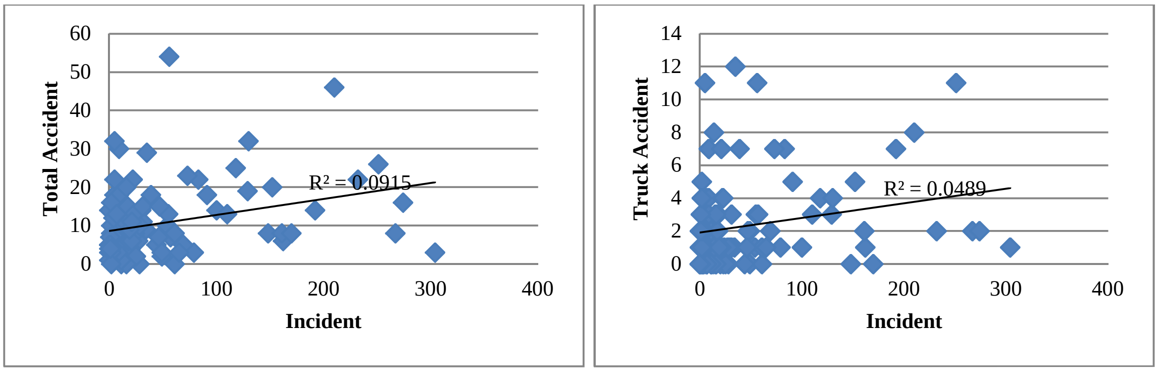


Figure I-1 Relationship between Total Accident and Harsh Braking Incident (left) and Truck Accident with Harsh Braking Incident Correlation (right) at Approaches Located on A and B class Roads

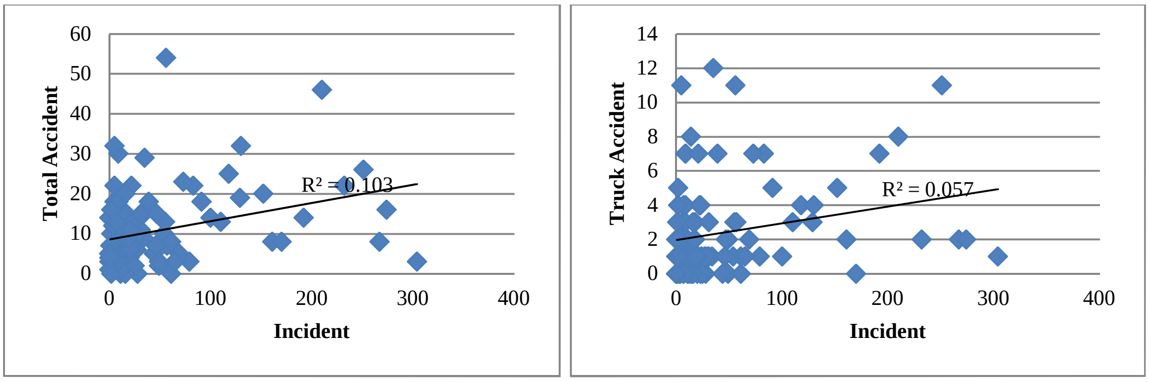


Figure I-2 Relationship between Total Accident and Harsh Braking Incident (left) and Truck Accident with Harsh Braking Incident Correlation (right) at Approaches Located on M class Roads

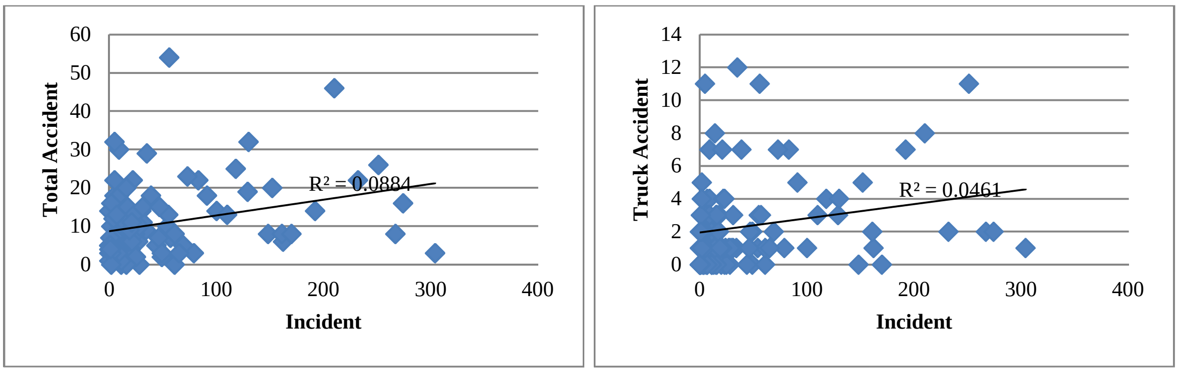


Figure I-3 Relationship between Total Accident and Harsh Braking Incident (left) and Truck Accident with Harsh Braking Incident Correlation (right) at Signalised Approaches

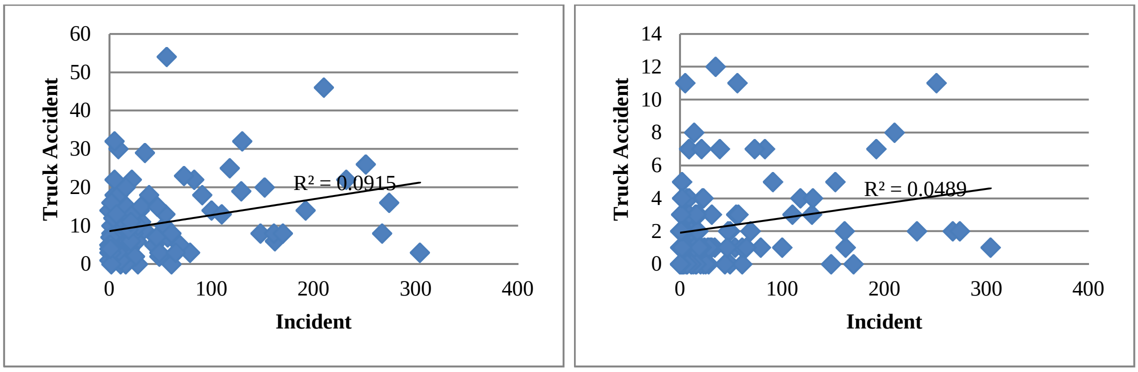


Figure I-4 Relationship between Total Accident and Harsh Braking Incident (left) and Truck Accident with Harsh Braking Incident Correlation (right) at Un-signalised Approaches

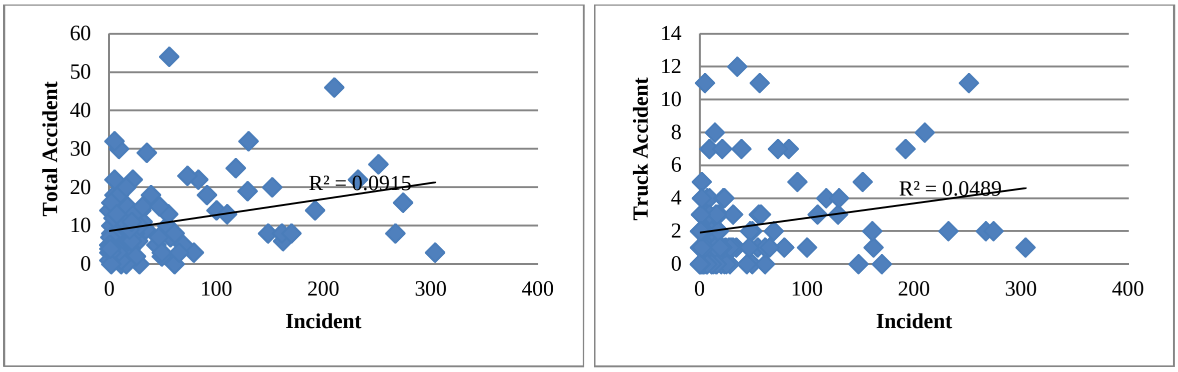


Figure I-5 Relationship between Total Accident and Harsh Braking Incident (left) and Truck Accident with Harsh Braking Incident Correlation (right) at Two-Lane Approaches

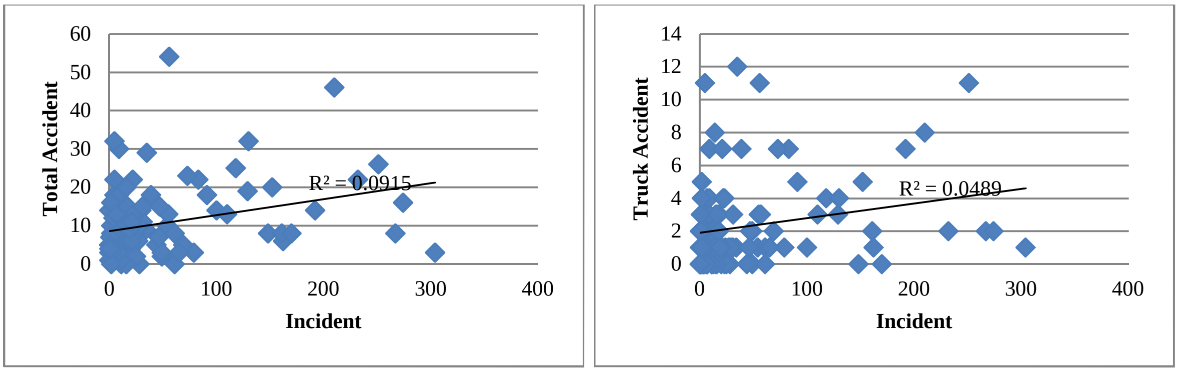


Figure I-6 Relationship between Total Accident and Harsh Braking Incident (left) and Truck Accident with Harsh Braking Incident Correlation (right) at Three-Lane Approaches